PRACTICAL ENERGY AUDIT MANUAL

Brewery Industry

Prepared by

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for

Indo-German Energy Efficiency Project

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PREFACE

Energy inputs - both electrical and fuel - are an essential part of manufacturing process, and expenditure on these inputs often accounts for a significant share of the manufacturing cost. This is compounded by the fact that the cost of energy is constantly escalating and will continue to rise.

Any saving in energy costs directly adds to the operating profits of the company. It probably requires less effort to improve profits through energy savings than by - reducing labour cost, increasing sales, increasing prices, reducing distribution costs, etc.

The main purpose of an energy audit is to systematically identify practical and feasible opportunities for saving all forms of energy in a plant and realise the benefit of cost reduction. Experience shows that as much as 10-15 percent of energy could be saved without any need of large investments, through energy audits.

The main objective of this manual is to familiarise the plant personnel in the techniques, methodology and approach to in-house energy audits. Since energy conservation is essentially a continuous exercise, it is inevitable that the plant personnel are able to regularly monitor trends in energy consumption and initiate remedial measures to improve energy efficiency.

Energy management is the philosophy of more efficient energy use, without compromising upon production levels, product quality, safety and environmental standards. However, as in any other commercial and economic facet, the concept of energy management is dominated by the cost efficacy - any project must be viable in financial terms before it can be transformed from paper to structure. Therefore, financial and technical evaluations are perceived to be essential, though necessitated to be secondary to the human resource aspect. It is inevitable that any such implementation has to overcome the Herculean hurdle of the ever-present attitude of "*no-change*" which, very often, needs a nudge to the "*change*" mode.

The energy management programme can be made "*self-financing*" - with the savings of the low-cost short term measures being utilised for the implementation of more capital-intensive measures.

Underlying the concept is a logical and comprehensive management approach. Experience shows that energy savings are significant and long lasting, when they are achieved as part of a comprehensive energy management programme. A systematic and structured approach is required to identify and realise the full potential of savings that can be achieved, mainly through low-cost measures. The basis of such a programme has to be a comprehensive and professional energy audit, in order to assess the current consumption pattern and identify potential opportunities to conserve energy, given the existing framework and infrastructure of the industry.

Specific energy consumption – the amount of energy consumed per unit of output – varies widely depending on the product in question, the type of manufacturing process, type of fuel, age of equipment, size of the plant and operating practices. The breweries are highly energy-intensive and therefore, have been taken up for a specific study in this document.

Studies have shown that, in most breweries, inadequate attention is paid to energy efficiency. In one case study of a brewery in Northern India, producing 15000 to 20000 kL of beer annually, various conservation measures could **save Rs. 0.3 million** worth of electrical energy annually, with an **investment of Rs. 0.2 million**, paying back in just seven months.

Since 1985, this industry has been growing at an estimated rate of 10-12% annually. Beer is a popular light drink. It is a carbonated alcoholic beverage, made from starchy raw materials like malt, barley, corn, rice, wheat, oats or potatoes. The alcohol content makes the beer strong or soft - diet beer has 5-8 percent, lager beer 8-7 percent, strong beer 13-14%. There is an increasing trend towards strong beer.

Beer production has evolved over the years from home brewing facilities to the present industrial manufacturing. Modern breweries are high technology ones, with sophisticated brewing and processing equipment. Today, the capacities of breweries in India range from 10 kL to 3 ML per annum.

Table 1.1: Installed Capacity of Major Companies

Company	Installed Capacity (kL/year)
United Breweries	14000
Mohan Meakin	48500
Skol Breweries	30000
Mount Shivalik	5000
Hindustan Breweries	5000
Mysore Breweries	20000
Kalyani Breweries	7822
Artos Breweries	15000
Ariem Breweries	10000
Indo Lowenbrau	5000
Punjab Breweries	5000
Sica Breweries	12500
Kesoram's Breweries	6000
High Range Breweries	1500
Jupiter Breweries	5000

India exports beer to many countries such as Bahrain, Bangladesh, Belgium, Ethiopia, Oman, Sri Lanka, UAE and USA.

Section 2 – The Brewing Process

There are no clear-cut differences between the various kinds of beers, and much of the distinction depends on customers' acceptance of the "*brand*" advertising, especially through local media and the all-pervading television. The main types of beer are:

Lagers: are beers produced with bottom fermenting yeast.

Ales: are beers fermented with top fermenting yeast. They have a higher alcohol content, up to 8%, but this is not a key characteristic. They are characterised by a shaped acid bite and a vinous flavour due to higher ester content.

Most beer making processes are traditional ones, handed down from generations. Beer production can be divided into two batch processes - malting and brewing. Malting, using barley or other cereals and water as raw materials moisturises and germinates the grains. The differences in the types of beer depend on the raw materials used, especially yeast, and the process. A brewery comprises four sections - the brew-house, the fermentation and maturation section, the bottling section and utilities. Fig. 2.1 gives a detailed flow diagram of the brewing processes.

2.1 Raw Materials

Traditionally, the raw materials for beer making are water, malt, hops and yeast, with various processing aids. Water is an increasingly expensive and fast-depleting commodity. Water for brewing must be potable and is often modified by filtration and inclusion of salts and organic acids.

Malt is a cereal, usually barley, germinated for some time and then dried. In the malting process, enzymatic reactions break down food polymers such as starch and protein to produce fermentable sugars. The friable malt is ground and extracted with warm water to give sweet wort. Special malts increase flavour and colour. Malt substitutes are also used sometimes, as cheaper alternatives. Hops are kiln-dried cones of a plant. They are used to cause post fermentation bitterness. Yeast is a living organism used to ferment the beer. Ale yeast is used at temperatures greater than 15°C and for large productions. Lager yeast is used for fermentation at less than 17^{0}C. Adjuncts are additions such as cereals, syrups and sugars to supplement the starch content. In India, typically cane sugar is used.

2.2 The Brewing Process

The four major processes in the industrial production of beer are malting, brewing, fermentation and conditioning. In malting, the barley is cleaned and graded, and submerged in water for 2 to 3 days to activate germination. The barley and steep water is loaded into a steep pool where the top foam is skimmed. The steep liquor is changed several times, with the temperature between 10 and 15°C. The liquor is then drained. The starch is converted into maltose. The moisture is then reduced from 45 % to 5 % by kiln-drying. The malt is dried and ground.

Brewing uses a mixture of malts and adjuncts called the grist. The grist is milled for better sugar extraction during mashing. After mashing, the juice or wort obtained is boiled to precipitate the proteins present. Hops are added during boiling to give a final flavour to the beer. Finally, the wort is cooled to avoid microbial infection, prior to fermentation.

At a temperature of 71ºC, the enzyme diastase of the malt splits the starch ($C_6H_{10}O_5$) of the grain into a sugar maltose ($C_{12}H_{22}O_{11}$) and glucose ($C_6H_{12}O_6$).It is cooled quickly and transferred into a cellar for fermentation by adding yeast. The chemical reaction during fermentation occurring at 7 to 12°C under refrigeration, yields alcohol (C_2H_5OH) and CO_2 as:

$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_5OH + 4CO_2$$

Thus 1 kg of maltose yields 0.538 kg of ethyl alcohol and 0.415 kg of carbon dioxide. The heat released during this reaction is about 650 kJ/kg of maltose reacted.

Separation of the wort from the grain can take more than two hours. The sweet wort is separated on lauter tuns by sedimentation. Proper lauter tun design and operation yields the best sweet extract, reducing the unwanted malt constituents. The sweet wort is boiled to precipitate proteins and stop enzyme action. During boiling, some sugars and hops can be added - hops are added to extract bitter resins and essential oils.

The brewing value is the alpha-acids fraction of the resins. An evaporation of 7 to 10 percent of the total volume and boiling time of 90-120 minutes is desirable. Steam is used as a heating agent in a jacketed vessel, usually made of copper or stainless steel. Evaporation rate, convection flow and hot break formation are important kettle attributes. Within the brew-house itself, the process of wort boiling is the most significant energy consumer. In recent years, maximum effort has been focused on this area to improve efficiency and thus, reduce energy consumption. Design considerations of the kettle must emphasise on energy efficiency.

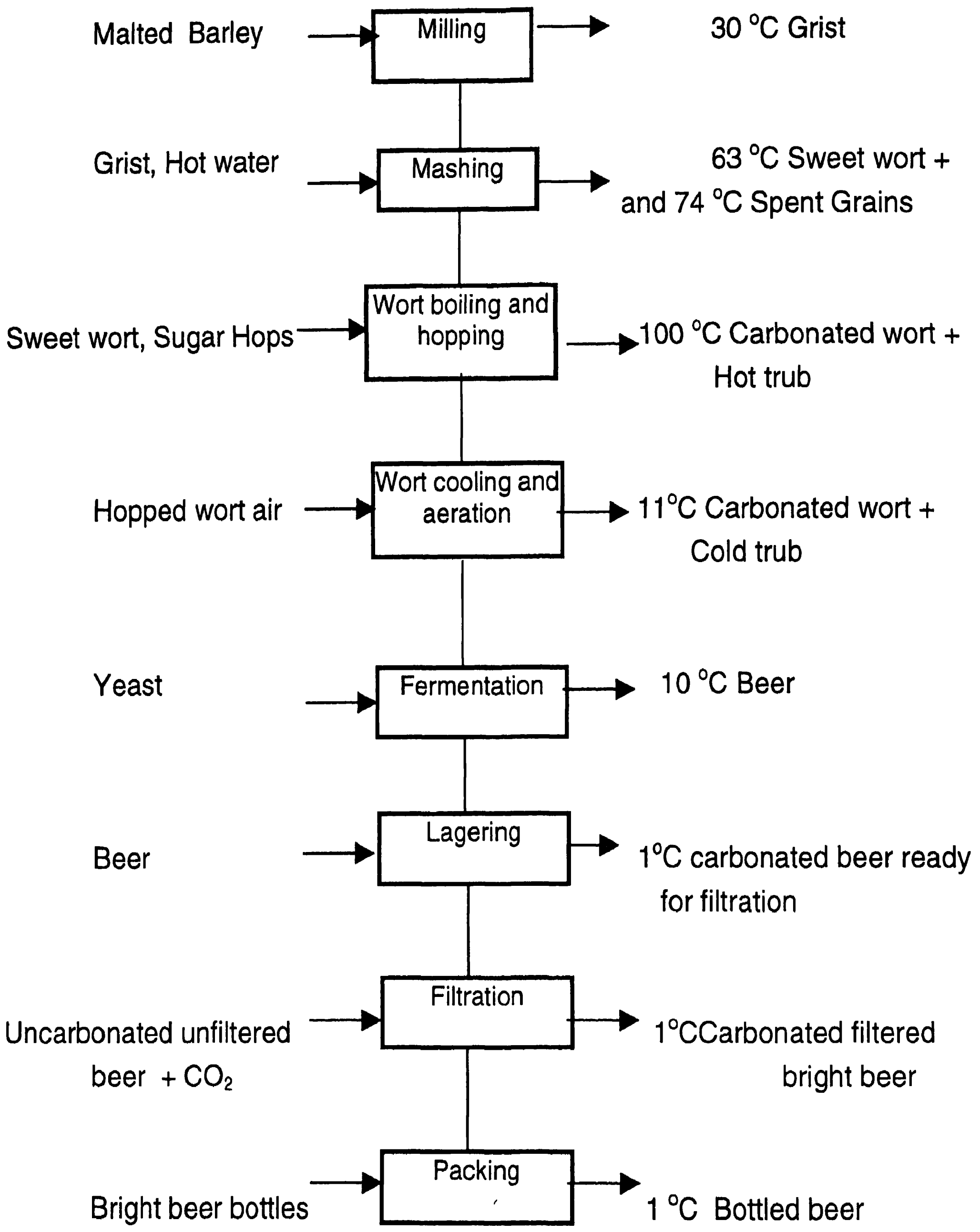
The boiled wort is centrifuged or passed through a whirlpool tank to remove the hot break or trub by sedimentation, filtration, centrifugation or whirlpool. Some brewers prefer to cool the boiled wort first and then separate the wort. The cleared hopped wort is cooled in a plate heat exchanger. Some protein and tannin material oozes out of the solution as a fine coagulum.

The carbohydrates in the wort, glucose, fructose, sucrose and maltose are the main source of carbon and energy for the yeast. The nitrogen sources are the amino acids in the wort. Lagering refers to the maturation and storage of the beer after fermentation. The cooled wort is aerated to increase dissolved oxygen to 8 - 10mg/l to help yeast growth. As yeast metabolism is fermentative, the carbohydrates are degraded to ethanol and carbon dioxide. Fermentation takes place in open or closed-jacketed stainless steel vessels, at 0 to 10°C for six days, circulating cold brine. The process is exothermic in nature. Continuous fermentation with a high concentration of yeast can be used. The yeast is separated from the beer by settling or centrifuging. The beer is cooled to 2°C and stored. Some brewers add sugar or sweet wort to induce a second fermentation in ales. After lagering, the beer is carbonated with carbon dioxide and conditioned at temperatures near 0°C to facilitate dissolution of the gas.

Before being sold, the beer is centrifuged, filtered and pasteurised and some conditioning agents are added to preserve it. The beer is chilled to near freezing and held there for several days to weeks, depending on the desired quality. Many chemical processes take place in this time, to make a clean, tasty, homogeneous beer. Extended conditioning time naturally clarifies the beer.

After filling, the bottles are pasteurised to ensure that the beer is sterile -- a minimum time and temperature is required to destroy all possible biological contaminants. Pasteurisers use minimum water and steam provided they are balanced and run at full capacity. They should not be frequently stopped and started. Water level controls should work properly with all instruments correctly calibrated. A flash pasteurisation unit can replace conventional tunnel pasteurisation, as it requires less space, steam and coolant.

Fig. 2.1 : Process Sequence in a Typical Brewery



The brewing process is fully described in Appendix 1, while Appendix 2 provides a glossary of the common terms used in the brewing process, as referenced from the Internet.

Section 3 - Energy System Profile

3.1 Energy Consumption Patterns

The energy consumption profile in a typical brewery is shown below:

Table 3.1 : Specific Energy Consumption (MJ/hl)

Section	Thermal	Electrical	Total
Brew house	133	1.6	134.6
Bottling	77	5.0	82.0
Refrigeration	-	63.5	63.5
Utilities	70	12.6	82.6
Lighting	-	4.0	4.0
Total	280	86.7	366.7

From the table, it is evident that the brew-house or more specifically, the wort kettle is the most energy-intensive equipment in the entire brewing process. Substantial savings can be made by heat recovery at the wort boiling stage.

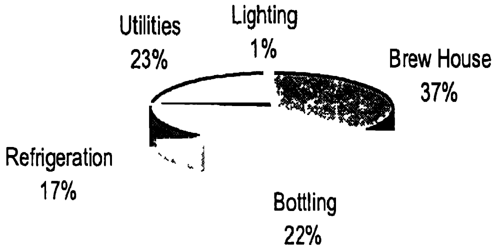


Fig. 3.1 : Consumption of Electrical Energy in a Brewery

3.2 Energy Intensive Processes

Some of the energy-intensive processes in a brewery include:

Malting Processes

Steeping: The barley is submerged in warm water for 2 to 3 days to activate germination. The moisture supports growth and biochemical alterations. The barley and steep water is loaded into the steep pool. A skimmer removes the foam on top. The process is repeated several times, changing the steep liquor. The steep temperature is maintained between 10 and 15°C.

Kilning: is a drying process using hot air to end germination and produce a dry, easily milled product. The moisture level is reduced from 42-46% to 5% for satisfactory storage. The drying process is energy-intensive.

Brewing Process

Lauter tuns: After mashing, the spent grains need to be removed from the wort. Separation of the wort from the grain can take more than two hours by sedimentation. Proper lauter tun design and operation yields the best sweet extract, reducing the unwanted malt constituents and energy consumption. Hot water sparging and the loss of heat retained in the spent grain account for a certain amount of thermal energy consumption.

Wort boiling: The sweet wort is boiled to precipitate the proteins (hot break) and to stop enzyme action. An evaporation of 7 to 10% of the total volume is desirable. A boiling time of 90-120 minutes is normal. Steam is used as a heating agent in a jacketed vessel, usually made of copper or stainless steel. Evaporation rate, convection flow and hot break formation are important kettle attributes. Within the brew-house itself, the process of wort boiling is the most significant energy consumer.

In recent years, maximum effort has been focused on this area to improve efficiency and thus, reduce energy consumption. Design considerations of the kettle must emphasise on energy efficiency.

Wort cooling: The cleared hopped wort is cooled in a plate heat exchanger. Some protein and tannin material oozes out of the solution as a fine coagulum or cold break. This can be removed completely by filtering the cooled wort to -5°C.

Beer conditioning

Pasteurisation: *After filling, the bottles are pasteurised to ensure that the beer is sterile -- a minimum time and temperature is required to destroy all possible biological contaminants. The process can be carried out before or after filling. Cans require a shorter pasteurisation sequence because of their superior heat conductivity. Pasteurisers use minimum water and steam provided they are balanced and run at full capacity. They should not be frequently stopped and started. Water level controls should work properly with all instruments correctly calibrated. A flash pasteurisation unit can replace conventional tunnel pasteurisation, as it requires less space, steam and coolant. If flash pasteurisation is carried out; filling conditions must be sterile.*

3.3 Auxiliary Consumers

Apart from the main brewing processes, the auxiliary equipment also consume substantial portions of both thermal and electrical energy. From the Fig. 3.1, it is evident that about 25 percent of the energy is consumed by various utilities such as:

- Electrical Drives
- Boilers and Steam Systems
- Pumps
- Refrigeration Systems
- Lighting
- Air Compressors
- Cooling Towers

These areas have been examined and recommendations made for conservation of energy through various investment measures.

Section 4 - Energy Conservation Opportunities

A comparison of the energy consumption rate between Indian and International brewery plants suggests substantial scope for energy savings by Indian plants. Comparative energy usage figures for Indian and British breweries are given in the following table.

Table 4.1 : Comparative Energy Figures

Description	India	International	
		UK (NPC Report)	Other norms
Fuel oil			
Litre/hl beer	7 to 15	-	-
MJ/hl beer	336 to 720	144	130-306
Specific electrical energy			
KWh/hl	24 to 44	-	-
MJ/hl	86 to 158	31	77-124

1 Process-Specific Conservation Areas

As in most other industries, simple modifications to the existing process conditions can achieve substantial savings in consumption of both thermal and electrical energy. This section discusses the actual conservation measures.

Other potential areas for energy conservation, besides the wort kettle, are the boiler-house, steam distribution, refrigeration, air compressors and electricity supply system. An efficient performance of all these can contribute sizeably towards overall energy savings, thus reducing specific energy consumption and related cost per unit of beer production.

In a brewery, the wort boiling and water heating account for more than 50% of the steam consumed in the entire plant. The energy content in kettle vapours, considered along with the total hot water consumption of the brewery, suggests a large potential to reduce steam consumption. Most new technology has been evolved on this concept of integrating the energy requirement in the brew house and water heating purposes. Some of these are detailed below in this section.

4.2 Cleaning in Place (CIP)

Short Term

The use of CIP installations for pipes and tanks is prevalent in the food industry and offers large saving in water consumption during cleaning operations. CIP methods can be used in various units. Some malting systems, such as the decked drums, can support CIP. Most methods use two washing streams - acidic and caustic - combined to avoid pH oscillation in the effluent. A reduction of water consumption, during washing does not imply reduction in pollution load.

4.3 Spray Condenser

Medium Term

One more method of heat recovery from the kettle vapours is to use a spray condenser. The efficiency of heat recovery from this system is as high as 90%. The spray condenser liquor is stored and used directly for mashing and sparging.

4.4 External Wort Boiling with Energy Recovery

Medium Term

Wort boiling accounts for almost half the thermal energy consumption of the brewery. As steam generation is often stretched to critical limits, wort boiling becomes a bottleneck. Not only does over production of steam become a waste of energy, it also has an impact on the environment, by way of effluent discharge. It is, therefore, important to examine this part of the process critically, to implement measures to improve efficiency and cost effectiveness, reduce wastage and meet statutory norms. Increased competition in the market implies production of quality brands at low costs, while complying with existing and projected environmental legislation. A co-operation between Alfa Laval and Entropie of France has seen the development of "Ejectotherm" a wort boiling system with energy recovery. (Appendix 3)

4.5 Continuous Wort Boiling

Long Term

The continuous wort boiling technique reduces energy cost by adopting integrated heat recovery practices. The wort is heated in two stages to a temperature of 120 C. At this temperature, it passes through a residence loop, designed for the required reaction period. The wort is then cooled in a plate heat exchanger (PHE), until it reaches the yeast pitching temperature. This technique produces good quality wort with a reduced energy requirement and variable evaporation rate. Energy savings of 85 % compared to a conventional system can be achieved.

4.6 Mechanical Vapour Recompression

Long Term

This system is a reliable and accepted technique in the brewery industry, which provides external boiling of the wort through compressed vapours. The vapours from the kettle are compressed up to 1.25 bar and used to heat the wort in the external boiler up to 102°C. The wort is subsequently expanded in the kettle at 100°C. The vapour condensate is collected in the condensate tank. By cooling it in a plate heat exchanger, heat is recovered from the condensate to preheat the water. A brewery utilising a high percentage of boil-off from the wort kettle, on a continuous basis over 24 hours may find mechanical vapour recompression more suitable. Appendix 4 elaborates the vapour recompression system. Energy saving to the tune of 25% can be achieved with this scheme. A case study describes typical systems with techno-economics.

4.7 Modern pressure boiling cum heat recovery system

Long Term

The energy storage system is adapted to store the heat recovered from the vapours. The water, which can be heated up to 96°C with vapours, can be used for mashing operations to reduce water usage. The investment for a heat exchanger unit and a storage vessel is not significant. Details of this system are placed at Appendix 5. Up to 50 percent saving in primary energy can be achieved, compared to conventional boiling.

Other new technologies in vogue overseas include continuous fermentation and flash pasteurisation. Vapour absorption refrigeration system is another area where waste heat can be utilised for refrigeration purposes. Some of these are detailed at Appendix 6.

4.8 Process Instrumentation and Control

Long Term

Accurate temperatures within ± 5°C are important in the wort boiling stages, to maintain the right flavour and taste of the beer. The use of programmable logic controllers (PLCs) to maintain this accuracy would avoid over-boiling in the wort, which would otherwise waste energy.

Wort cooling is an extremely time-specific operation, which can also be controlled by PLCs. Recovery of heat at this stage to re-use the hot water for steeping is a critical operation which can be PLC controlled. The exact saving that can accrue would require a detailed analysis of the avoidable wastage. However, human interface can be provided with PLCs, for greater consistency in quality.

4.9 Pinch Analysis or Process Integration for Energy Economy

Heat integration involves the optimal balancing of heat sources and sinks in a process complex with the aim of maximising recycling of energy and minimising energy inputs. The application of a technique called "Pinch Analysis", for process integration in the case of a brewery can save energy. Details of the Pinch Analysis techniques are placed at Appendix 7.

Present-day economic pressures force brewers to constantly seek ways and means to reduce capital expenditures and improve upon the overall operational productivity. The design and construction of larger fermenting and storage vessels to keep batch processing in tune with current output volumes, can reduce both capital and production costs, with an interesting challenge to the economics of continuous processing. Accelerated batch and greater volume processes, preferably combined with the concept of high gravity brewing, are thus favoured.

A Universal Tank, or Uni-Tank, for short, is one in which a Universal Process, or Uni-Process, can be conducted. It offers substantial versatility with better product quality. The Uni-Process is fully described in Appendix 8.

4.10 Boilers

The thermal energy for the brewery is obtained from low-pressure steam, generated by the boilers. Steam consumption at the brew house and bottling is around 60% of the total steam input in a typical brewery. Thermal energy constitutes about 75% of the total energy consumption by the typical brewery. Therefore, energy efficient steam generation is the starting point for thermal energy savings.

Boilers are sensitive equipment, whose efficient maintenance and running contributes towards fuel energy conservation. The checklists highlight various simple measures to be considered for effective energy conservation in boiler operations. Beyond simple housekeeping measures, various operational and equipment modifications, if warranted, can improve the performance of the boilers. The type and condition of boilers, including the firing system and combustion controls, fuel characteristics, heat recovery system and operating practices determine the extent of energy savings. Only a complete engineering evaluation will reveal the type and nature of improvements with benefits and costs involved. The boiler fuels are deliberated upon in Appendix 9, while Appendix 10 discusses the combustion process and equipment in detail, with combustion related problems and remedies.

Opportunities for Energy Conservation

Various energy audits of boiler systems have identified various losses in the steam system. The first step to an audit of the boiler system would be the evaluation of the efficiency of the system, by quantifying parameters such as fuel consumption rate, operating pressure, feed water flow rate, dry and wet bulb temperature, flue gas components and surface temperature. The various boiler losses include dry flue gas losses, hydrogen loss in fuel, water loss in air, fuel losses and surface heat losses. These are discussed in detail in Appendix 11.

Steam is produced in the boiler so that its latent heat can be utilised in the production processes. The boiler plant, the steam mains, distributing lines, steam utilisation equipment and condensate return system should all be arranged and properly managed to give the best overall efficiency to the process plant. The important sources of energy losses in the steam network are listed below:

- *Radiation losses from improper insulation or lack of insulation*
- *Heat losses due to improper sizing and length of steam pipes*
- *Steam leaks from valves, flanges, gauges, joints*
- *Improper selection, incorrect location and malfunctioning of traps. Improper location and capacity of air vents*

In most industrial boiler operations, there is a significant potential to improve the energy efficiency. The extent to which operational and equipment modifications can *improve the performance is determined by the type and condition of the boiler, the firing system, combustion controls, fuel employed, existing heat recovery equipment and general efficiency-related operational practices. However, in order to determine whether modifying operating practices or installing auxiliary equipment is needed, it would be necessary to conduct a complete engineering evaluation from the standpoint of technical feasibility, economics, system capability and viability.*

The performance deficiencies can be heat transfer related, combustion related or a result of unnecessary losses such as high auxiliary power consumption, excessive blow down, steam leaks and defective insulation.

Based on the audits and case studies, certain recommendations, pertaining to the boiler systems are briefly discussed below.

Boiler Tune-up

rational

It is a cost-effective method of achieving efficient operation and fuel savings. Adjustment and maintenance of fuel burning equipment and combustion controls permits operation with the lowest practical excess air, thus reducing stack losses.

Boiler set-up for low excess O_2 is accomplished through a series of tests conducted on boiler. During the process, the CO_2 in stack gas is measured at intervals of 15 minutes and the secondary air damper is progressively closed till the CO_2 level rises to the optimum level. This threshold level is generally around 12-13% in the case of oil-fired boilers, as in typical breweries. The boiler is allowed to stabilise and then CO is measured. If necessary, the secondary air can be increased to reduce the CO in the stack below the threshold level.

This test can be repeated for different firing rates within the operating range, and depending on the control system design. Sufficient trials should be made to ensure that, after the final control adjustment, optimum excess O_2 conditions are maintained at all the intermediate firing rates.

Once the minimum O_2 is established, the next step is to determine the appropriate O_2 margin or operating "cushion" above the minimum O_2 where the boiler can be routinely operated. This is the lowest practical O_2 for the boiler and is the optimum setting for high efficiency (and in most cases, lowest NO_x emissions). This cushion of a slightly higher level of oxygen is to ensure that :

- *Rapid boiler modulation does not result in smoking or combustibles in flue gas.*
- *There is no play in the automatic controls. Excessive play should be immediately corrected.*
- *Normal variations in atmospheric conditions do not change excess O_2 on units not equipped with temperature and pressure-compensated combustion air systems. This is a very important, but often neglected, factor. Extreme variations in ambient conditions can easily produce changes in excess O_2 of 1% or more.*
- *If fuel properties change, there is sufficient excess air.*

The fuel oil-to-air ratio controls on modern boilers should be able to maintain the recommended excess air through much of the turndown ratio of the burner, but excess air increase at low turndown rates.

Combustion controls regulate the quantity of fuel and air flows in a boiler. In choosing the most effective type of control system, one must consider boiler capacity, steam demands, expected performance levels, costs, pollution regulations and safety. It is economical to equip small units (which produce 25,000 pounds of steam per hour) with fuel saving control systems, but care should be taken to avoid a specification that is not viable to operate.

Various levels of sophistication in controlling excess air are available:

- *The most inexpensive method is to use a portable oxygen analyser using alkaline pyrallogol and draft gauge called a Fyrite Kit. Periodic readings guide the operator to adjust levels accordingly.*
- *A continuous oxygen analyser and a permanently mounted draft gauge, both with local readouts, are most commonly used. The operator can continuously monitor and adjust the level.*
- *In the continuous oxygen analyser system, a remote controlled pneumatic damper positioner is added. Draft and oxygen readouts are located in a control room, enabling the operator to control a number of firing systems.*
- *The most sophisticated control system is the automatic stack damper, which is usually justified only for a large system.*

The first system makes a reduction of 20 percent possible. The second and third systems further reduce the excess air level by 10 to 15 percent. The most suitable system must be determined by calculating the economics of each case.

Some other combustion control systems and burners are detailed in Appendix 12.

Improving Maintenance

In many cases, a substantial improvement in boiler efficiency is possible without purchasing new equipment or retrofit devices. Through proper maintenance, efficiency losses can be minimised, leading to efficient utilisation of existing steam generating equipment. Proper maintenance can also have an important bearing on plant reliability, plant loading and safety.

Efficiency degradations can be traced directly to problems of mechanical linkages controlling fuel and air flows, malfunctioning or poorly calibrated combustion analysers, inoperable or maladjusted dampers or boiler instrumentation, the cleanliness of boiler tubes, boiler heat loss during blow down and other such factors.

Other Equipment

Boiler efficiency can be improved in oil-fired systems by use of special oil atomisation and viscosity control systems. Proper pre-treatment and atomisation of the oil are vital to reduced excess air operation.

Heat Transfer Related Problems and Remedies are discussed in Appendix 13.

Steam leaks

Short Term

These are obvious heat losses, which should be corrected as quickly as possible. Small leaks inside the boiler may go undetected, unless signs are found during a shutdown. Largerleaks may be detected by the noise of the escaping steam, increased vapour emission from the stack or increase in requirement of makeup water. Water or steam leaks in coal fired boilers can cause extensive damage if allowed to continue. An obvious steam leakage occurs at pipe joints, flanges, valves and unions, but steam losses from malfunctioning steam traps are less evident. Steam leaks must be rectified at the earliest.

Need for Water Treatment

Natural water contains impurities, both in solution and suspension. If water is used directly, in steam or hot water boilers, severe corrosion takes place, and scale formation prevents effective heat transfer, thus wasting energy. Poor water treatment results in increased blow-down from the boiler. The presence of impurities in the feed water would cause priming and foaming in the boilers.

The undesirable effects of these impurities are :

- *Scale formation*
- *Corrosion*
- *Priming*
- *Foaming*
- *Caustic embrittlement.*

Depending on operational requirements, boiler shutdown for cleaning and maintenance should be optimised, for a more economical operation.

Guidelines for day-to-day operation

- *Check and record flue gas temperature at the stack regularly.*
- *Clean the heat transfer surface as often as possible, especially if temperature increases more than 40°C above normal.*
- *Measure the flue gas temperature at the same load level and operational conditions for comparison of values.*
- *Look for ash deposits. If there are any deposits, examine burner condition, adjustment and combustion control. Look for reasons for the overheating - possibly waterside deposits or insufficient excess air.*
- *Look for carbon deposits in the gas passages. Check for combustion conditions.*
- *In case of excessive fouling, check burner condition, its adjustment as well as combustion control.*
- *If sulphur is present, avoid acid dew point conditions.*
- *Remove deposits, as far as possible without entering flue ways, by using roots blowers and vacuum cleaning equipment.*

Air Infiltration

To achieve higher boiler efficiency, air infiltration to the furnace must be minimised. The boiler economiser and air heater casings should not have air leaks. Warped or cracked access-doors that do not seal properly, as well as missing sight glass in view ports, patch leaks in ductwork, especially on the upstream of an air heater or economiser must be replaced as soon as detected.

The air heater leakage in tubular air heaters is normally less than 1%. However, low exit gas temperature can lead to cold end corrosion and increased leakage. Rotary air heaters (Ljungstrom type) require seals to prevent forced draft air from entering the gas stream. Since these seals are between stationary and moving parts, they are not perfectly tight and are also subject to wear. Normally, the leakage is 7 to 15%, depending on the size of heater and pressure differential between gas and air. Worn seals or improperly adjusted seals can double the leakage. Since leakage in both tubular and rotary type heaters occurs after the gas passes over the heating surface, there is no loss in heat recovery. But, the additional airflow that the forced draft fans must supply and the additional gas flow through induced draft fans, if present, represents additional auxiliary power consumption and could possibly influence unit capacity. Air heater leakage can be verified by measuring the excess air entering and leaving the air heaters. Inspection of tubes or seals should be made at annual shutdowns.

Waste heat recovery from flue gas

a) Boiler Feed water preheating using economiser

Medium Term

Typically, the flue gases leaving a modern 3-pass shell boiler are at temperatures of 200 to 300° C. Thus, there is a potential torecoverheat from these gases. The flue gas exit temperature from a boiler is usually maintained at a minimum of 200° C, so that the sulphur oxides in the flue gas do not dew out and cause corrosion in heat transfer surfaces.

When a clean fuel such as natural gas, LPG or gas oil is used, the economy of heat recovery must be worked out, as the flue gas temperature may be well below 200°C. Flue gas economisers have been used for a long time, on both shell and water tube boilers of older designs. Most consist of large cast iron heat exchangers, as the iron is more resistant to the acid corrosion, that is inevitable at *start up and shut down. In general, for every 1° C increase in feed water temperature, there is an approximate 4° C drop in flue gas temperature.*

The potential for energy saving depends on the type of boiler installed and the fuel used. For a typically older model shell boiler, with a flue gas exit temperature of 260° C, an economiser could be used to reduce it to 200° C, increasing the feed water temperature by 15°C. Increase in overall thermal efficiency would be 3%. For a modern 3-pass shell LTHW (low temperature high pressure water) boiler firing natural gas with a flue gas exit temperature of 140° C a condensing economiser would reduce the exit temperature to 65° C increasing thermal efficiency by 5%.

b) Combustion air preheat

Combustion air preheating has always been treated as a poor cousin of the economiser, because air pre-heaters are large and, on the whole, less efficient. In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20° C. Most gas and oil burners used in a boiler plant are not designed for high air-preheat temperatures. Usually, a maximum increase of 50° C is all that can be tolerated.

The source of combustion air preheat is usually the :

- *remnant heat in the flue gases*
- *higher temperature air from the top of the boiler house*
- *air drawn over or through the boiler casing recovering part of the shell heat losses.*

Modern burners can withstand much higher combustion air preheat, so it is possible to consider such units as heat exchangers in the exit flue as an alternative to an economiser, when either space or a high feed water return temperature make it viable.

The saving achieved depends on the type of system installed. In the two most common cases - (a) ducting hot air from the top of the boiler house and (b) drawing combustion air over/through the boiler casing - typically one or two percent improvement in thermal efficiency, respectively, can be expected.

Reducing blow down heat loss

It is necessary to blow down boilers regularly, to remove the sludge deposited by precipitated salts and maintain water conditions laid down by the manufacturer, thus avoiding priming and carry-over into steam mains. Salt precipitation on waterside heat transfer surface would also impair the heat transfer between the flue gas and the water. But the level of blow down should be kept as low as possible. The recommended levels of total dissolved solids must be maintained, to avoid unnecessary loss of sensible heat. The possibility of converting the heat loss from blow down to some useful purpose, such as feed water pre-heating, should be examined.

Blow down systems can be intermittent or continuous processes, and can be manual, semi-automatic or fully automatic. A TDS test should be carried out, prior to blow down, so that the blow down time can be adjusted for changes in average boiler load conditions, which occur on a day to day basis.

The boiler blow down requirement can be calculated from the following equation.

$$\%\ \text{Blowdown} = \frac{S_f \times 100}{S_b - S_f}$$

Where, S_f = *TDS in feed water in mg/l or PPM*
S_b = *Desired TDS in boiler in mg/l or PPM.*

The total dissolved solids (TDS) in feed water, at the boiler feed tank, vary as the boiler load. Thus the amount of condensate returned also varies. When sampling the feed water, this must be taken into consideration, to determine whether it is typical of the average boiler operating conditions.

The blow down system can be made fully automatic by installing a TDS monitoring facility to over-ride the timer, in the event of variation from the desired TDS level. Proper checking and maintenance of quality of boiler and feed water, maximising condensate return and smoothening of load swings will minimise the loss. The installation of blow down heat recovery systems also helps to control the loss. For heat recovery, continuous blow down systems are preferred. In its simplest form, a continuous blow down system consists of a manual set-valve adjusted, after regular boiler water tests.

Radiation and Convection Heat Loss

Short Term

The external surfaces of a shell boiler are hotter than the surroundings. The surfaces thus lose heat to the surroundings depending on the surface area and the difference in temperature between the surface and the surroundings.

The heat loss from the boiler shell is normally a fixed energy loss, irrespective of the boiler output. With modern boiler designs, this may represent only 1.5% on the gross calorific value at full rating, but will increase to around 6%, if the boiler operates at only 25 percent output.

Reduction of Boiler Steam Pressure

Short Term

This is an effective means of reducing fuel consumption, if permissible, by as much as 1 to 2 %. Lower steam pressure gives a lower saturated steam temperature and without stack heat recovery, a similar reduction in the temperature of the flue gases temperature results.

Steam is generated at pressures normally dictated by the highest pressure/temperature requirements for a particular process. In some cases, the process does not operate all the time, and there are periods when the boiler pressure could be reduced. The energy auditor should consider pressure reduction carefully, before recommending it. Adverse effects, such as an increase in water carryover from the boiler owing to pressure reduction, may negate any potential saving. Pressure should be reduced in stages, and no more than a 20-percent reduction should be considered.

Soot Blowers

Short Term

Soot blowers should be checked for improper operation. If ash deposits are allowed to accumulate on boiler tubes, heat loss through the flue gas increases. 1/8th inch of soot can be considered equal to an inch of insulation

Boiler Replacement

Long Term

The potential savings from replacing a boiler plant depend on the anticipated change in overall efficiency. A change in a boiler plant can be financially attractive if the existing plant is :

- *old and inefficient*
- *not capable of firing cheaper substitution fuel*
- *over or under-sized for present requirements*
- *not designed for ideal loading conditions*

These reasons will be apparent from the detailed energy audit, and calculating the change in efficiency can make an estimate of the saving :

$$\text{Fuel saving} = \frac{(\text{Existing fuel use})(\text{efficiency of new plant - efficiency of old plant})}{(\text{efficiency of new plant})}$$

No decision to change a plant should be taken based on the detailed energy audit alone. When the results of the detailed energy audit indicate that it would be financially attractive to replace a boiler plant, a feasibility study should be conducted. The feasibility study should examine all implications of long-term fuel availability and company growth plans. All financial and engineering factors should be considered. Boiler plants traditionally have a useful life of well over 25 years; hence, replacement must be carefully studied.

Effect of Peak Load on Boiler Efficiency

Load fluctuation in a boiler is one of the main causes of heat wastage. Smoothening out the peaks and valleys in a boiler load curve would result not only in fuel savings, but also increased production and improved quality.

a) Effect of peaks on boiler output:

A sudden increase in steam demand causes the boiler pressure to drop. The burner thus, fires at its full rate. However, the pressure continues to drop as the boiler takes time to respond. With a sudden drop in the boiler steam demand, the steam flow falls, but the burner continues to fire, as the boiler pressure is still low. The abrupt drop in steam consumption does not the allow burners sufficient time to respond to the changes, and hence the boiler pressure over shoots the relief valve setting. The steam valve, thus, blows off, wasting steam.

b) *Effects of peaks on boiler efficiency*

Since boiler combustion efficiency is affected by the burner turndown ratios, frequent fluctuations of steam pressure and demand, call for accurate control and operation. Otherwise, losses ranging from 8 to 12 percent could occur. Apart from this, radiation losses could occur on low loads, and safety valves can blow off, resulting in losses as high as 15 percent and 10 percent respectively.

Effect of Boiler Output on Efficiency

The maximum efficiency of the boiler does not occur at full load, but at about two-thirds of the full load. If the load on the boiler decreases further, efficiency also tends to decrease. At zero output, the efficiency of the boiler is zero, and any fuel fired is used only to supply the losses. The factors affecting boiler efficiency are :

a) *As the load falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the same heat transfer area, reduces the exit flue gas temperatures by a small extent, reducing the sensible heat loss.*

b) *Below half load, most combustion appliances need more excess air to burn the fuel completely. This increases the sensible heat loss.*

The net effect of these factors is to produce a load/efficiency curve. It has been generally noticed that the fall in efficiency begins to become serious below about a quarter load, and as far as possible, operation of boilers below this level should be avoided.

Proper Boiler Scheduling

Since the optimum efficiency of boilers occurs at 65-85% of full load, it is usually more efficient, on the whole, to operate a fewer number of boilers at higher loads, than to operate a large number at low loads.

Operational

It is advantageous to distribute load to the most efficient boilers, and to operate boilers at loads where the efficiency is highest. When choosing boilers to operate at higher loads, due consideration should be given to the comparative performance curves of the boilers. Generally, newer units with higher capacity are more efficient than older units with smaller capacity. The smallest and least efficient unit should be reserved for plant load saving.

Moreover, boilers that operate at higher pressures are usually more efficient, and these should be used to supply as much of the plant demand as possible. However, high-pressure steam should be used efficiently, as otherwise, it can contribute to the losses.

Optimum Steam Utilisation

Short Term

A sudden pressure drop sometimes takes place in the steam line of the brew-house when keg filling is underway. To avoid this drop, keg filling and bottling should not be two simultaneous operations.

Condensate Recovery from Mash Tank

Steam condenses and gives up its latent heat, resulting in hot condensate. Depending upon steam pressure, this condensate can contain around 25% of the heat supplied by burning fuel in the boiler. The condensate, being a pure form of water can be used directly as boiler feed water, thus saving raw water and chemicals required in water treatment. Every 6°C rise in the feed water temperature can result in about 1% savings on the fuel consumption in the boiler. The payback period for installing a condensate recovery system depends on the quantum of condensate recovered, the temperature of condensate, type of boiler and plant layout. Proper handling of the condensate is important to derive maximum benefit. This will mainly involve proper sizing of the condensate pipes.

Reduction in Steam Utilisation to Generate Hot Water

Medium Term

The usual source of hot water generation is the plate heat exchanger, where cold water picks up heat from the wort cooling process. The heat recovery of the plate heat exchanger is the main source, while additional hot water is generated by utilising steam to heat cold water. Optimising the heat recovery from the plate heat exchanger can reduce this utilisation of steam to a considerable extent. This has an additional benefit of reducing the refrigeration load on the system also.

Waste Heat Recovery from Wort Kettle Vapours

Long Term

As mentioned earlier, the wort boiling is the most energy-intensive process in the entire brewing. The boiling temperature of the wort kettle is around 100°C. The vapour emitting from the wort kettle contains substantial sensible and latent heat. This heat can be utilised to preheat the next brew wort during transfer from the pre-tank to the wort kettle, by installing a storage tank. The subsequent brew wort has to pass through a shell and tube heat exchanger to pick up heat. A rise of at least 20°C has been possible.

4.11 Refrigeration and Air Conditioning

As in the entire food and beverage sector, refrigeration is an important component of energy component. Refrigeration not only helps in proper preservation of the liquor in a brewery, but also enables certain chemical reactions to take place at low temperatures.

Cooling can be provided by a variety of systems; the most prominent in India and world-wide is the vapour-compression system using Chlorofluorocarbon (CFC) working fluids. These could be eventually replaced by methods such as the Montreal Protocol.

It has been estimated that refrigeration systems account for about 5% of the electricity consumption in the industrial sector. However, in many chemical and food processing industries, refrigeration accounts for a large share of the total electricity consumption. In breweries, refrigeration accounts for 50-60%, of the total energy consumption.

Cooling can be provided by a variety of systems; the most prominent in India and globally is the vapour-compression system using Chlorofluorocarbon (CFC) working fluids. These could be eventually replaced by methods such as the Montreal Protocol. (Appendix 14)

Figure 4.1 shows the standard vapour-compression refrigeration system.

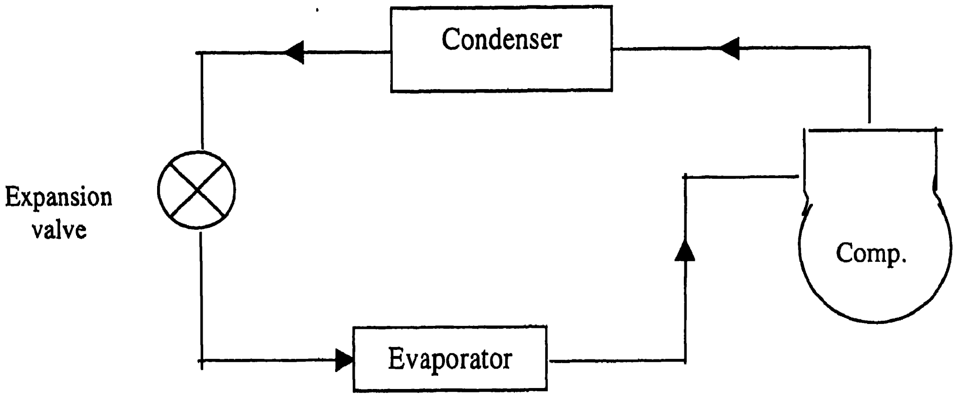


Fig. 4.1 : The Standard Vapour Compression Cycle

In the vapour compression system, energy is absorbed by liquid refrigerant boiling in a heat exchanger known as evaporator. This energy comes from the substance to be cooled - brine, water or air. The compressor, which is driven by a prime mover, raises the pressure and temperature of the refrigerant. The compressed vapour is then cooled and condensed in a heat exchanger called condenser and gives up its latent heat, usually to air or water. The liquefied refrigerant pressure is reduced through a throttling device and sent back to the evaporator to complete the cycle. To avoid high compression ratios, it is necessary to have several stages of compression for very low temperature applications.

The efficiency of the system is usually determined by the coefficient of performance (COP). It is an expression of the cycle efficiency and is defined as the ratio of the heat absorbed in the refrigerated space to the heat energy equivalent of the energy supplied to the compressor. That is,

$$\text{Coefficient of performance} = \frac{\text{Heat abosrbed from refrigerated space}}{\text{Heat equivalent of energy supplied to compressor}}$$

$$= \frac{\text{Useful cooling effect (kW)}}{\text{Total power into system (kW)}}$$

In real systems, the compressor motor represents only part of the power input and running cost. Pumps, fans, crankcase heaters all consume power and in some cases also contribute to the heat load on cooling circuit.

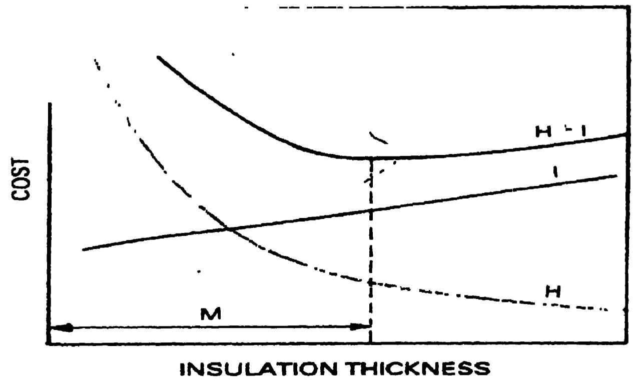
A tonne of refrigeration is the refrigeration produced by melting 1 tonne of ice at a temperature of 0°C (32° F) in 24 hours. It is a heat removal rate equivalent to the removal of 3,000 kcal/h or 12,560 kJ/h or 3.5 kW (12,000 BTU/h).

Thermal insulation plays a key role in energy conservation. The basic function of thermal insulation is to prevent flow of unwanted heat energy from the surroundings to the system. Since entrapped air in cellular or fibrous structures reduces conductive and convective heat gain, insulating materials like expanded polystyrene (thermocole), glass, wool etc., are used. Water vapour in air tends to migrate towards cooler surfaces due to vapour pressure difference and condense, thus replacing the entrapped gases/air in the insulation. The water will also expand and destroy the insulation. Proper care must, therefore, be taken to provide a barrier that will prevent entry of water vapour into the insulation.

A cold insulation must have low thermal conductivity and high water vapour resistance and durability at low temperature. Glass wool and thermocole are the most common insulation used in the industry on ducts, chilled water lines, tanks and refrigerant suction lines. The physical and thermal properties of the insulating materials are given in Appendix 15. Other factors to be considered while selecting insulating materials are fire resistance, mechanical strength, cell structure, available forms and cost.

Cold system insulation is designed to prevent moisture from condensing on the colder surfaces and therefore, the desired outer surface temperature is 1° or 2°C above the dew point. The dew point is calculated from dry and wet bulb temperature and relative humidity from the psychometric chart.

Heat flow from the surroundings can be minimised by using thicker layers of insulation but this will entail higher costs. Economic thickness of insulation (ETI) is defined as that thickness of insulation at which the cost of the next increment in thickness is just offset by the energy savings due to that increment over the life of the project. The ETI is calculated by plotting the cost of insulation and cost of refrigeration required to compensate the heat gain at a particular insulation thickness. Then total cost is plotted and the thickness at the minimum value of the total cost is the ETI.



I = Cost of Insulation, H = Cost of heat gain
I + H = Installation cost, M = Economic thickness

Fig. 4.2 : Insulation Thickness Vs Cost

Given the average climatic condition in India, the recommended thickness of insulation for various materials against different storage temperatures are given below.

Table 4.2 : Recommended Thickness of Insulation for Different Storage Temperatures with Outside Mean Temperature of 40°C

Name of the material	Minimum Density kg/m^3	Thickness in mm						
		Temperature Range, °C						
		- 30 to - 20	- 20 to - 15	- 15 to - 4	- 4 to + 2	2 to 10	10 to 16	Above 16
Cork	164	225	200	150	125	100	75	50
Expanded polystyrene	18	175	150	125	100	75	50	40
Resin bonded glass wool	32	175	150	125	100	75	50	50
Foam glass	127	300	275	200	150	125	100	10
Resin bonded mineral wool 48	175	150	125	100	75	50	50	-
Foam concrete	320	-	-	-	-	150	100	75
Saw dust and rice husk	160	-	-	-	-	250	150	100
Fibre insulation board 260	-	-	-	-	150	100	50	-

The first step towards assessment of energy conservation opportunities in an existing installation is to determine the operating tonnes of refrigeration vis-à-vis installed capacities.

$$\text{Tonnes of Refrigeration} = \frac{\underline{\text{Chilled water flow x Temp drop across chiller (Deg.C)}}}{3000}$$

Reasons for deviation can be analysed and corrective action taken after the load is established. The next step involves assessment of actual tonne of refrigeration in user department/section.

The power consumption by the compressor is strongly influenced by the choice of evaporator and condenser temperatures and design. For a fixed suction pressure, higher discharge pressures or temperature decrease refrigeration capacity and increase specific power consumption. Condenser temperature should be maintained as low as possible.

Table 4.3 : Effect of Variation in Condenser Temperature on Compressor Power Consumption (Devki, 1992)

Sl.No.	Condensing temperature (^oC)	Refrigeration Capacity (Ton)	Specific power consumption (%)	Increase in kW/ton (%)
1	26.7	31.5	1.17	-
2	35.0	21.4	1.27	8.5
3	40.0	20.0	1.40	19.6

It is estimated that for a given evaporator temperature, every 5.5°C increase in condensing temperature reduces refrigeration capacity by about 6%. Similarly, suction pressure depends on evaporator temperature and pressure. As suction pressure is reduced, the specific volume of refrigerant increases and consequently, volumetric efficiency decreases. This leads to reduction in capacity and increase in specific power consumption. Reduction in suction temperature has the same effect. The following table gives the effect of suction temperature and specific power consumption (Bagnoli et al, 1984).

Table 4.4 : Effect of Variation in Suction Temperature on Specific Power Consumption kW/TR of Different Compressors Types*

Suction temperature, °C	Screw Compressor**	Reciprocating compressor	Centrifugal compressor
4.4	1.1	1.05	0.9
- 17.8	2.1	2.00	1.8
- 40.0	4.3	-	3.0

* Based on condensing temperature of 40.5 °C.

** Screw compressor equipped with intermediate port and economiser

Hence, it is important that cooling load be estimated carefully and suction temperature maintained at the highest possible level. The table below gives the effect of variation in evaporator temperature on compressor power consumption. (Devki, 1992).

Table 4.5 : Effect of Evaporator Temperature on Compressor Power Consumption

Evaporator Temperature, (⁰ C)	Refrigeration Capacity (Tonne)	Specific power consumption (kW/tonne)	Increase in kW/tonne (%)
5.0	67.58	0.81	-
0.0	56.07	0.94	16.0
-5.0	45.98	1.08	33.0
-10.0	37.20	1.25	54.0
-20.0	23.12	1.67	106.0
Condenser Temperature : 40 ⁰ C			

For low temperature applications involving high compression ratios, and for wide temperature requirements, it is preferable, due to equipment design limitations and often economical to employ multi-stage reciprocating machines or centrifugal/screw compressors. The following table gives the effect of poor maintenance on specific power consumption (Devki, 1992).

Table 4.6 : Effect of Poor Maintenance on Compressor Power Consumption

Condition	Evaporation Temperature.°C	Condensor temperature.°C	Refrign Capacity tonnes	Sp. Power consmn, kW/tonne	Increase in kW/tonne %
Normal	7.2	40.5	17.0	0.69	-
Dirty cond.	7.2	46.1	15.6	0.84	20.4
Dirty evap.	1.7	40.5	13.8	0.82	18.3
Dirty cond. And evaporator	1.7	46.1	12.7	0.96	38.7

* *15 tonne reciprocating compressor based system. The power consumption is lower than for systems typically available in India. However, the percentage change in power consumption is indicative of the effect of poor maintenance.*

Part load operation is important because most refrigeration applications have varying loads. The load may vary due to variations in temperature and process cooling needs. Capacity regulation through speed control is the most efficient option. It should be ensured that the lubrication system is not affected. In centrifugal compressors, it is usually desirable to restrict speed control to about 50% of the capacity to prevent surging. Below this level, vane control or gas bypass can be used for capacity modulation.

It is more efficient to operate a single chiller at full load than to operate two chillers at part load. Isolation valves must be provided to ensure that chilled water does not flow through chillers not in operation. This reduces power consumption of the pumping system. It may be economical to provide a separate smaller capacity chiller, which can be operated using on-off control, to meet peak demands, with larger chillers meeting the base load.

A chilled water storage facility can be used to meet the requirement, without operating chillers continuously. The low tariffs offered by some electric utilities for night operation can be utilised gainfully for a storage facility.

The absorption refrigeration machine is a water-chilling package that uses heat directly without a prime mover, thus utilising heating facilities on a full time, round-the- year basis. It can be installed anywhere due to its compact size and vibration free operation. It uses the cheapest, safest and most available of all refrigerants, ordinary tap water. Its absorbent is a simple salt.

A few pertinent recommendations for conservation of energy are discussed below.

(i) Routine Measures:

It has been practically found, during various audits, that periodic cleaning of the Plate Heat Exchanger (PHE) in the NH_3 refrigeration systems increases efficiency and improves the TR generation. Periodic cleaning of condensors and chillers in Freon R_{22} systems and maintaining the level of the refrigerant has a significant impact on efficiency.

(ii) Cold Water Recovery at PHE

Medium Term

The load on the system can be lowered by optimising cold water recovery at the PHE. Not only does this reduce the refrigeration load but also the steam required for hot water generation.

(iii) Interlock between compressor and cooling tower fan

Medium Term

An interlocking system between NH_3 refrigeration compressor and cooling tower fan ensures that the whenever the compressor is idle, the cooling tower fan does not run idle.

(iv) Improvement in insulation

Medium Term

Improvement in heat insulation can very effectively reduce energy consumption. Other measures to reduce heat ingress would also be very pertinent and feasible.

4.12 Pumps

Machines used to provide fluids with the energy to flow from one point to another against the resistance of the system are generally subdivided into pumps, fans and blowers. Pumps increase the potential energy of a fluid to raise it to a higher level. The transfer takes place by increase in the kinetic energy or velocity of the fluid. In a brewery, pumps are mainly used to transfer the wort and brewed liquor from one stage to another. The important design parameters are the impeller diameter, blade shape, blade angle, blade width and blade length. The important parameters in selecting a pump are flow and head required, specific gravity and viscosity of fluid, nature of solid and efficiency of the pump.

Pumps are classified, as centrifugal and positive displacement pumps rotary & reciprocating. Fans are broadly classified, based on orientation of air or gas flow, as centrifugal, axial flow and mixed flow. The pump efficiency at a given operating point is the ratio of the useful power transferred to the liquid stream to the power supplied to pump shaft.

The various losses in pumps are hydraulic, leakage, mechanical and disc friction losses. The various affinity laws also affect the performance of the pumps. Illustrative case studies pertaining to energy conservation opportunities in pumping systems are given in the relevant manual on Pumps. A few of the measures are briefly touched upon in this section.

(i) Maintenance Measures:

Short Term

Before assessing the measures for energy savings in pumping, it should be ensured that the water intake flow meter in the water circulation circuit is in good working condition.

(ii) Optimal Pump Loading:

Short Term

The beer handling pumps are constructed from expensive materials. Hence, if they were not optimally loaded, impeller trimming would be the best alternative.

(iii) Replacement with High Efficiency Pumps:

Medium Term

It is worthwhile considering replacing multiple pumps in the water circulation line with a single high-efficiency mono-block pump. This ensures the pump is optimally loaded and results in energy savings.

(iv) Layout of Piping:

One aspect of energy conservation in the pumping circuit is to ensure that unnecessary bends and restriction in the pipelines are removed, in order to increase efficiency.

4.13 Electricity Supply System

The use of energy efficient electrical equipment with improved operating practices helps to control losses in distribution and equipment. Reduction in maximum demand load, based on improved equipment demand control, power factor correction, improving power factor, energy efficient motor selection and utilisation, and improved lighting practices can result in overall reduction in electricity usage by 3 - 5%.

Integrated load management can effectively control maximum demand and its appearance during peak/off-peak periods of the power system. When running a number of large motors, it is advisable to stagger them where feasible, with a suitable time-delay to minimise simultaneous maximum demand of these motors. Non essential loads can be shed temporarily to reduce peak demands.

It is necessary to maintain standard voltage levels by rationalising tap positions of transformers. This would also minimise energy losses in cables and bus bars. Higher voltage results in lower line current and losses.

Cable/Line losses are the sum of I^2R or resistance losses. Resistance is inversely proportional to cross sectional area of conductor and hence, higher the cable size, lesser would be the energy loss. If cable size is inadequate, (which also depends on the length of distribution line), it is advisable to either replace the same with the higher size cable or provide additional circuits depending on the field conditions.

Power factor is the ratio of actual power in kilowatts to apparent power drawn from the line in kVA. Improvement in PF facilitates better utilisation of existing capacity and some reduction in resistance line losses. The higher the PF, better is the electricity use. PF can be improved by using capacitors, synchronous motors, synchronous condensers and other high PF equipment in series with the load.

4.14 Electric Drives

Most motor driven equipment such as fans, pumps and compressors are subjected to varying load. These systems are designed for a maximum duty condition, which rarely occurs, with the result that they run for long periods at less than maximum flow. The reduction in flow is achieved by dampers, throttle valves or by-pass systems, all of which are energy inefficient. Substantial savings can be made if the system is altered, so that control is achieved by varying the speed of the motor instead. Some conservation measures include :

(i) Housekeeping Measures:

Short Term

An inventory of motors with name-plate details would help in taking judicious replacement decisions. Periodic cleaning of motor fans with ventilation grids, checking of noise level, bearing alignment and lubrication, tightening of terminals will ensure trouble free operation.

(ii) Motor Protection Relays:

Medium Term

For important and strategic motors, it is advisable to use motor protection relay to avoid motor burning, which could prove costly both in terms of loss of motor as well as production downtime.

(iii) High Efficiency Motors:

Long Term

Motors should be chosen considering machine load at start and during running. The annual cost of electrical energy consumed by a motor is 2-3 times the initial cost of the motor itself. This emphasises the need for choosing energy efficient motors, even if they are slightly more expensive. The energy consumption in motors is based on the efficiency of the driven equipment and the system. One of the main factors of inefficiency is routine under-loading. Many times, motors of higher capacities are selected just to meet initial torque requirements.

Table 4.7 : Savings from Higher Efficiency Motors (rating 20 HP/14.9 kW)

Parameters	$\eta = 87\%$	$\eta = 93\%$
Initial cost (Rs.)	24000	32000
Annual capital charges @ 20% for 10 years life	4800	6400
Input power (kW)	17.15	16.04
Power consumption/year in units (8000 h)	137200	128320
Electrical charges @ Rs. 4/- per unit	548800	513280
Total recurring cost (Rs.)	553600	519680
Total savings/year (Rs.)	-	33920

Replacing motors driving fans/compressors/pumps etc. by high efficiency motors can reduce energy intensity. Motors may weigh a little more, be slightly larger in dimension and cost about 30% more. However, they use less electricity and operate on a higher power factor.

4.15 Lighting System

An energy audit of the lighting system will also reveal the efficiency of the existing system. Although lighting contributes very little to the overall energy profile, this is also an area of little attention and consequently, the most neglect.

The low efficiency incandescent and fluorescent lamps such as tungsten filament lamps (GLS) can be replaced by fluorescent lamps or high-pressure mercury vapour lamps (HPMV) or by high-pressure sodium vapour lamps (HPSV) or blended light lamps as a plug in replacement. Most discharge lamps display a gradual reduction in light output over the years. These should be replaced at the end of their economic life even if they do not fail.

A slight reduction in operating voltage, in case of fluorescent tubes, would result in savings without affecting lighting levels appreciably. A separate voltage regulator, which supplies about 380/390 volts to the lighting circuit, be used. In large/medium scale industries, where the lighting consumption is high, it would be economically viable and technically feasible to have a separate 11 kV/240V – 3 phase transformer, exclusively for lighting circuits. Scheduling controls help eliminate unnecessary use of lighting. Some recommendations for conservation of energy include:

(i) Standard Operating Routines:

There should be a "Switch Off" campaign or installation of automatic switching or dimming equipment. The use of local switches for both lamps and fans should be encouraged. This will enable control of lighting near the source itself.

(ii) Housekeeping Measures:

Reduction in height of the ceiling can reduce 20-30% energy consumption by way of lower lighting requirement. Painting walls and ceiling with light colours can reduce artificial light requirements. Unnecessary lamps can be removed or switched off, preferably by a timer switch. Natural light can be effectively used by providing large fibreglass skylights and high openings in the walls. Periodic cleaning of lamps and windowpanes will ensure full utilisation of daylight and artificial lights.

Section 5 - Water Conservation

There is a current public perception that breweries are "large water consumers and polluters". Although this is not entirely unfounded, there can be an opportunity to change this perception of breweries as "an ecologically sound industry, conserving and renewing natural resources." Throughout major breweries globally, world research is focusing on minimising or eliminating discharge of process-waste waters to the receiving environment.

5.1 Water Requirements

Breweries require high quality water for the process, while operations such as floor and equipment washing could use low-grade water. For the latter, sand-filtered water or biologically treated process water can be used. However, it should be ensured that product and reclaimed waters are not mixed.

The maximum consumption of water in breweries is perhaps in the washing of bottles, which requires considerable amounts of caustic and water. Many large breweries recycle cleaning solutions in an effort to conserve water.

By-Product recovery is another aspect of water conservation. Wastes from the brewing process, such as grains, hops, trub containing proteins, yeast, press liquors which contain fat, fibre, proteins and carbohydrates make excellent poultry feed. The wet by-products, with a moisture content of 75-80 % can be used as excellent cattle feed after being pressed. After these by-products are remained, the water can be recycled. Plate and frame filters are more effective, in terms of water use, than lauter tun filters for this recovery.

Usually, the liquids from the pressed spent hops are high-strength wastes, which can be recycled back into the brewing process right after the wort leaves the brew kettle.

5.2 Waste Water Treatment

Recovery of spent grains, excess yeast, spilled product, waste filter aid involves a combination of screening, settling or filtration, evaporative concentration and drying. The liquid steam from the screening and pressing can be concentrated in multiple effect evaporators to 20-30% solids and dried for marketing as distiller's dry solubles.

Centrifuges can effectively reduce the volume of sludge requiring disposal and the resultant effluent is more amenable to treatment by sedimentation. Recovery of solid wastes from concentrated streams is more effective.

Cooling water and boiler blow-down containing corrosion inhibitors and biocides can be discharged directly to the polishing lagoons. The caustic cleaning solutions help to maintain the pH balance.

Other conservation measures include process design modifications and water management programmes, auto shut-off valves, alterations to process filtering for maximum product recover, forced air cleaning in pre-washing containers, elimination of once-through cooling, air-cooling in place of water cooling, use of recycled water for cooling and low-flow plumbing fixtures. Anaerobic digestors are separately dealt with in Appendix 16

The case studies have been specifically chosen to substantiate and indeed validate the recommendations discussed in the previous chapters.

6.1 Industry case study 1

A brewery in India had a production capacity of 450000 hL of Beer (Normal beer with 6.5% alcohol and extra strong beer with 8.0 -9.5% alcohol).

Refrigeration is required for:

- Wort chilling (raw water & chilled water)
- Fermentation process (Brine & AHU) 7 day process
- Para-flow filtering

while air-conditioning is required for:

- Hops room ,
- Cold fermentation room (New ones do not require)
- Lagering rooms

There are seven vapour compression refrigeration systems using ammonia as a refrigerant. Six are reciprocating type and one is a screw type compressor. One system is exclusively meant for the Ice Building Tank (IBT) whereas the other systems chill brine ($CaCl_2$, 25% Conc.) to - 9°C. The total refrigeration requirement is200 - 250 TR.

The detailed energy audit could make the following recommendations:

Dispense with cold fermentation Room-AHU by proper insulation of exposed domes of horizontal fermenting vessels.

Estimated Savings in Refrigeration = 10 TR
Energy Savings @ 1.5 kW/TR = 15 kW
Total pumping power for AHU of Old fermentation rooms, Hops Room and Yeast Tilting Vessels = 9.23 kW
Estimated savings in pumping Power @ 50% = 4.60 kW
AHU fan Power = 2.5 kW
Total Savings = 22.1 kW
Annual savings @ 8000 hours = 176,000 kWh
Energy cost @ Rs. 3.50 / kWh[#] = Rs. 616,000

[#] *All energy tariffs are those prevailing at the time of the audit and are consequently subject to an upward revision.*

Cost of insulation:
Effective area per vessel = 6 m^2
Area for 18 vessels = 108 m2
Cost of 100 mm thermocole = Rs. 1200/m2
Investment = Rs. 129,600
Simple Payback Period = 2.5 months

b) Reduce condenser water pump for one system from 15 kW to 11.5 kW

Existing pump power = 15 kW
Proposed pump rated power = 11.5 kW
Percentage loading = 75 %
Savings in power = 3.5 x 0.75 = 2.625 kW
Annual savings @ 4000 hours = 10,500 kWh
Cost savings @ Rs. 3.50 / kWh = Rs. 36,750
Investment
Cost of Pump = Rs. 30,000
Condensor Descaling Cost = Rs. 5,000
Total Investment = Rs. 35,000
Simple Payback Period = Just less than a year

c) Water Savings Achieved by Condensing Wort Vapour.

The wort vapours generated in the unit are presently exhausted to the atmosphere. The vapours can be recovered by installing a thermo-compressor where these vapours can be compressed to 1.7 kg/cm^2. This steam is returned to the wort kettle for indirect heating of the mash. The condensate from these vapours can be collected and returned to the boiler through the condensate recovery tank. Hence both steam and soft water savings are achieved.

Capacity of Wort Kettle = 300 hl
Capacity Utilised = 250 hL
End Product = 225 hL
Vapours Generated = 25 hL
Boiling Time = 2 hours
Temperatures of Wort = 96 - 100 °C
Steam Pressures
Side Heating = 1.5 kg/cm2
Centre Heating = 5.0 kg/cm2
Heating Time

Side Heating = 3.5 hours
Centre heating = 2.0 hours
Input material to kettle = Wort
Batch Time = 3.5 hours
No. of batches per day = 3
Basis per Batch
Number of Wort batches per year = 1000
Vapours generated = 2.5 t
Temperature of the exhaust vapours = 76° C
Enthalpy of vapours = 630 kCal/kg
Total heat in vapours = 1575000 kCal

If these vapours are compressed to form steam to 1.7 kg/cm2, then
Heat in vapours
Steam pressure = 1.7 kg/cm2
Temperature of steam = 128°C
Enthalpy of steam = 650.7 kCal/kg
Heat in steam = 1626750 kCal
Heat input required = 51750 kcal
Theoretical energy required = 60 kWh
Efficiency of thermocompressor = 60%
Total energy per batch = 100 kWh
Savings in steam = 2.5 t/batch
Total batches per year = 1000
Cost of steam = Rs. 600 /t
Annual cost savings = Rs. 15 lakh
Savings in water = 2.5 t/batch
Savings by recycling condensate = 2500 t
Cost of water = Rs 50/t
Annual Cost Savings = Rs1.25 lakh
Total Annual Savings = Rs. 16.25 lakh

Operating Cost of Thermocompressor
Energy Consumption per cycle = 100 kWh
Annual energy consumption = 100000 kWh
Cost of Power @ Rs. 3.5/kWh[#] = Rs. 3.50 lakh
Net savings = Rs. 14.75 lakh
Equivalent Furnace oil Savings = 205 kL

[#] *All energy tariffs are those prevailing at the time of the audit and are consequently subject to an upward revision.*

Investment required = Rs. 20 lakh
Simple Payback Period = 1.35 years

d) Application of MVR

MVR came into vogue in breweries in Western countries as result of the continuous quest for energy savings and improvement in quality of beer. In India, wort kettle recompression system is not used in any of the breweries. Installation of MVR in wort boiling will result in:

- Increased production due to reduction in heating time
- Reduction in water consumption
- Reduction in thermal energy up to 95%
- Reduction in specific energy consumption by 50%, compared to conventional brew house.

The table gives the energy balance of the wort kettle of a typical brewery in India, after installing mechanical vapour re-compression.

Particulars	Kcal/h
Heat input	
Primary energy	7174
Electrical energy: power for MVR compressor	397
Heat output	
Transfer & transmission losses	.1794
Brew house losses	4521
Heat recovery by cooling condensed vapor	825
Unused or lost vapour	431
Re-cycled heat components	
Production of warm water	6818
Recovery of heat from MVR	8134

Since total evaporation from the kettle is twice as high for the vapour recompression in this special case, that much more warm water is produced. A characteristic feature of the MVR is its great flexibility, which makes it a good choice for both breweries with various brands and those trying to achieve high energy savings and reduced emissions.

Energy Saving Potential

The potential to conserve energy varies according to both the process and the capacity. Other benefits include:

- Utilisation of condensate from MVR for heating cold incoming wort.
- Availability of hot condensate water above 90°C for cleaning kettles.
- More reliable operations in the brew house
- Increase in production capacity by reduction in batch time
- Saving in water demand.

The energy saving potential for a typical brewery producing 45000 hl annually would be:

Particulars	Existing system (per batch)		Proposed system (per batch)	
Steam	4.4 t	Rs. 2640	0.6 t	Rs. 360
Steam-Hot water generation	0.6 t	Rs. 360	0.1 t	Rs. 60
Electricity	5 k Wh	Rs. 17.5	100 kWh	Rs. 350
Water	34.5 t	Rs. 1725	32 t	Rs. 1600
Total	Rs. 4742		Rs. 2374	
Annual Cost	Rs. 8.536 million		Rs. 4.266 million	

Total annual savings	: Rs. 4.27 million
Investment required	: Rs. 6.00 million
Simple payback period	: 1.5 years

6.2 Industry case study 2

The detailed energy audit of another brewery located in South India with a production capacity of 150000 to 200000 hL per annum was also conducted with the following recommendations emerging out of the study.

a) Replacement of raw water pumps with a high efficiency pump.

Flow	= 76.03 m^3/h
Head	= 8 m
Power Consumption	= 6.94 kW

Considering motor efficiency at 80%, the pump operating efficiency was rather low at 30%. Replacement with a 60% efficient pump would consume 3.46 kW

Power Savings = 3.48 kW
Annual Energy Savings @ 6000 hrs = 20900 kWh
Cost of Saving @ Rs. 4.65 /kWh[#] = Rs. 0.97 lakh
Investment for 2 pumps = Rs. 0.50 lakh
Simple payback period = 6 months

b) Replacement of existing single stage air compressor with a two-stage air compressor.

The brewery has a single stage air compressor with a design FAD of 5.13 m^3/min. The actual FAD was measured at 3.67 m^3/min. The proposal was to replace this single stage air compressor with a two-stage air compressor.

Power Savings = 16.37 kW
Considering 70% savings feasible = 11.46 kW
Annual Energy Savings @ 3000 hrs = 34000 kWh
Cost of Savings @ Rs.4.65/kWh[#] = Rs. 1.60 lakh
Investment = Rs. 3.00 lakh
Simple payback period = 2 years

The reduction in specific energy consumption would be 5.32 kW (100 m^3/h). The annual saving of Rs. 0.16 million could be achieved with an investment of Rs. 0.3 million, for a simple payback period of less than two years.

c) Energy saving opportunities in the boilers

The brewery has two types of boilers, viz., Nestler and Thermax. Both boilers are operated under high-flame and low-flame conditions, using furnace oil as fuel. It was observed that both boilers were not tuned properly, leading to a mismatch in the air-fuel ratio. This resulted in higher than design consumption of fuel. The tuning of the boilers to maintain the CO_2 level in flue gas around 13% could effect substantial savings in fuel.

[#] *All energy tariffs are those prevailing at the time of the audit and are consequently subject to an upward revision*

Combustion Parameters

Nestler Boiler

Particulars	Before	After
Low Flame		
% CO_2	7.5	11.3
Flue Temp °C	218	220
Excess air %	110	40
High Flame		
CO_2	13.4	13.4
Flue Temp °C	264	264
Excess air %	18	18

Thermax

Particulars	Before	After
Low Flame		
% CO_2	10.3	13.1
Flue Temp °C	187	188
Excess air %	54	20
High Flame		
% CO_2	7.5	12.8
Flue Temp °C	215	214
Excess air %	111	24

The impact of adjusting the boilers to optimum excess air is given in the table below.

Boiler	Units	Boiler # 1915 (Nestler)	Boiler # 2039 (Thermax)	Total
Duration of boiler on low flame	%	40	30	-
Duration of boiler on high flame	%	60	70	-
Efficiency **before** implementation	%			
During low flame		78.7	83.8	-
During high flame		82.7	78.5	-
Weighted average		81.1	80.1	-
Efficiency **after** implementation	%			
During low flame		83.3	85.6	-
During high flame		82.7	84.2	-
Weighted average		82.9	84.6	-
Improvement achieved in efficiency	%	1.8	4.5	-
Boiler operating hours per year	hours	8000	8000	-
FO consumption - before implementation	kg/h	189	228	417
	l/h	199	240	439
Savings in OF	kL/year	29.01	86.97	116
Cost of OF	Rs./kL	7320	7320	-
Cost savings	Rs Lakh/year	2.12	6.37	8.49
Investment	Rs. Lakh	0	0	0
Simple payback period	Months	Immediate	Immediate	Immediate

From the above table it is clear that substantial savings can be achieved by adjusting the excess air supplied to the boilers. The investment required is nil and the payback period is immediate.

6.3 Industry case study 3

The other plant dealt in this section is a brewery in Nepal that produces beer from imported malt. The installed capacity of the plant is 1,20,000 hL/year. The major energy sources to the process are electricity, HSD and LDO.

Electricity is used in driving motors of refrigeration compressors, pumps, blowers, air compressors, bottling and for lighting. HSD is used for raising steam and for power generation through DG sets. Sometimes LDO is used for boiler due to its price difference. (NRs : Nepali Rupees). The plant has two boilers of 1.2 tph and 2.0 tph capacity respectively. The first boiler generates steam for the brew house, while the latter operates with the former, when both the production area and brew house are in operation. The excess air was about 250% and flue gas temperature was 206 °C.

Some of the audit recommendations have been briefly described below.

a) Controlling Excess Air

Controlling excess air for the boiler could bring about a significant improvement in the efficiency of boiler # 2, as shown in the table below, while also reducing the HSD consumption. The savings achieved for 2500 annual operating hours for this boiler are detailed below.

Parameter	Before	After	Improvement
HSD Consumption in litres /h	44	38.1	5.9
Efficiency , %	73.28	86.71	13.43
Power consumption of blower, kW	2.3	1.5	0.8

A) Annual HSD savings = 14.75 kL
Annual savings (@ NRs. 16.50 per lit.) = NRs. 2.4 lakh

B) Annual power savings = 2000 kWh
Annual savings (@NRs. 4.40 per kWh) = NRs. 8,800

Total cost savings (A+B) = NRs. 2.5 lakh

Investment for fyrite kit = NRs. 20,000
Simple Pay back period = Immediate

b) Recovery of Condensate from Mash Tank

It was found that condensate from the mash tank was being drained to effluent plant. The condensate is about 14 litres per brew. This condensate could be recovered by connecting the condensate outlet to the common condensate line at hot water tank.

Quantity of condensate	= 14 lit. Per brew
No. of brews per year	= 1000
Total condensate from mash tank	= 14 kL. Per year
Measured condensate temperature	= 92 ^{0}C
Boiler make-up water temperature	= 29 ^{0}C
Heat available in condensate	= 8,82,000 k.cal.
By recovery of condensate savings in fuel	= 96 lit per year
Annual cost savings (@ NRs. 16.50 per lit.)	= NRs. 1584/-
Investment required	= Marginal
Simple pay back period	= Nil

c) Reduction in Steam Consumption by Optimising PHE Recovery

As per PHE specifications:
During wort cooling through PHE, 86 hl per hour cold water temperature will rise from 27 ^{0}C to 81.5 ^{0}C considering installation of flow transducer and adjusting flow of cold water (86 hl/h), temperature can be raised to 78 ^{0}C without steam requirement.

If hot water produced from PHE 86 hl, then the cold water requirement for the process that consumes steam to raise its temperature, will be 16 hl instead of present 22 hl.

Total hot water required per brew	= 102 hl
Hot water temperature	= 78 ^{0}C

Present PHE recovery

Cold water flowrate to PHE	= 79.97 hl
Initial temperature of water	= 29 ^{0}C
Final temperature of water	= 72 ^{0}C

Remaining water required for brew will be heated by steam.

Excess process water requirement = 22 hl
Steam consumption for heating cold water = 207 kg
Steam requirement for hot water generation = 299 kg

Reduction in steam consumption

Steam required to raise 16 hl
cold water temperature to 78 ^{0}C = 150 kg
Reduction in steam consumption = 57 kg

However, since water is not required to be raised to 78 ^{0}C, but only to 72 ^{0}C, the actual reduction is much more.

Actual reduction in consumption = 92 kg

Reduction in steam consumption = 149 kg/brew
Enthalpy of steam at 1.5 kg/cm^2 = 648 k.cal./kg
Reduction in HSD consumption = 10.5 lit. per brew
No. of brews per year = 1000
Annual fuel savings = 10.5 kl
Cost savings (@ NRs. 16.5 per lit.) = NRs. 1.73 lakh
Investment for flow transducers = NRs. 3.00 lakh
Simple pay back period = 1.7 years

d) Wort Kettle Vapour Recovery

During wort boiling, the wort level was found to reduce from 77 hl to 70.5 hl. The amount of vapour generated during boiling was 6.5 hl. The vapour contains a good amount of sensible and latent heat. The available energy can be used to preheat the wort from 76 ^{0}C to 99 ^{0}C.

Vapour released from wort kettle = 650 kg.
Temperature of exhaust vapours = 100 ^{0}C, 1 bar
Heat required to pre-heat
wort from pre run tank to wort kettle = 187726 k.cal. (A)
Total heat available in the vapour = 403200 k.cal.

Considering 50 ^{0}C condensate will be drained out.
Heat carried away by condensate = 32500 k.cal.
Total heat available after condensate is
Drained out = 370700 k.Cal
Considering efficiency of shell and tube
heat exchanger = 60%
(make-up water will carry some heat)
Useful heat from vapours = 222420 k.cal. (B)

The amount of heat available (B) is higher than the heat required to raise wort temperature (A) from 76 0C to 99 0C.

Heat required to rise wort temperatur = 187726 k.cal.
Latent heat of steam at 4.5 kg/cm^2 = 501 k.cal. per kg.
Present Steam requirement = 375 kg.
Enthalpy of steam at 4.5 kg/cm^2 = 656 k.cal. per kg.
Equivalent reduction in HSD = 26.8 lit.
No. of Brews per year = 1000
No. of Brews preheated by vapour recovery = 840
Annual fuel savings = 22.5 kl.
Annual cost savings (@NRs. 16.50 per lit.) = NRs. 3.71lakh

Investment required
Cost of insulated tank = NRs. 8.0 lakh
New pump cost = NRs. 1.0 lakh
Installation and piping = NRs. 3.0 lakh
Heat exchanger = NRs. 3.0 lakh
Total Investment = NRs. 15.0 lakh
Simple pay back period = 4.0 years

Some case studies from the Internet have been culled and placed here. However, more details will probably be available with a visit to the relevant web site.

6.4 Gas Engine Co-generation

Gas engines, using clean fuel at a high thermal efficiency which is second only to diesel engines, are suitable for small-scale co-generation systems (CGS) (1000 kW or below). Therefore, packaged type gas engine CGSs incorporating new technology have been developed by manufacturers.

In a Japanese brewery, a 810 PS (596 kW) gas engine with a cooling system using boiling water for a CGS is mounted on a vibration-proof foundation together with a 560 kW generator. It is installed in combination with a steam and water drum, which recovers low-pressure steam at one bar directly from the engine's cooling water. The exhaust gas from the engine is used to generate medium pressure steam at eight-bar with a waste heat boiler, and to preheat boiler feed water with an economiser. The CGS is equipped with a NO_X removal three-way catalytic converter, a silencer and other necessary control systems, and can be monitored from a central control room.

The system has run smoothly since 1988, round-the-clock, logging over 18,000 hours. The power generating efficiency, heat recovery efficiency and overall efficiency of the CGS during this period were 31.3, 45.6 and 76.9% respectively.

The electricity generated by the CGS supplied 25% of the required power, with the remainder purchased from an electric utility. The generated steam satisfied 6-10% of the brewery's requirements.

The gas engine is a Caterpillar 4-cycle engine with a water-cooled turbocharger (G399ta-Hcer), fuelled with 13A town gas (natural gas with a calorific value of 46.1 MJ/Nm^3 supplied by local gas company. The waste heat boiler is a once-though boiler, capable of generating 390 kg/h of 8-bar steam. The steam and water drum can generate 720 kg/h of 1 bar steam.

The CGS consumes 156 Nm^3/h of 13A gas and 19 kW of electricity, producing net 541 kW of electricity, enabling the brewery to cut its contract demand by 10% or 500 kW (from 5000 kW to 4500 kW).

The three-way catalytic converter keeps NO_X concentrations in the exhaust gas of the engine at 150 ppm. Vibration-isolating and noise-reducing measures prevent the environment surrounding the brewery from being affected.

The total investment cost was ¥ 166 million. The operating costs are ¥ 45.3 million/year and the maintenance costs are ¥5.8 million. The investment costs can be paid back within four years by saving ¥39 million and by tax benefits toward co-generation systems.

6.5 Combined Heat and Power System

This study examined energy and cost savings by installing a combined heat and power system (CHP). The company (in UK) produces malted barley for the beer and lager brewing industry. The energy required for malting varies over the production cycle from 6,000 to 400 kW, over a 24-hour period. Prior to installation of CHP, electricity was supplied from the grid and heat was produced by two 3.8 MW boilers.

The decision to install a CHP was taken to reduce energy consumption. The company decided to cover the site base load, but did not attempt to meet peak demands. The system is a gas-fuelled reciprocating spark-ignition engine; heat is recovered from engine exhaust gas and cooling water via two separate heat recovery circuits.

Some initial problems were undoubtedly present, mainly in the jacket water radiator system. However, these were overcome by increasing the size of the radiator and, later by modifications to the software controlling the system. In general, operation has been satisfactory and led to replication at another company site.

A strategic advantage, which was not considered while planning, was continuity of supply. Previously, two lengthy power failures had resulted in huge losses and the installation of CHP safeguards against such potential losses. It is thought that any process operators with a continuous or extended demand for low or medium temperature hot water could benefit from this technology.

CHP plant: SITA gas-fuelled reciprocating spark-ignition engine, maximum power output 760 kWh. Compared to conventional electrical supply and boiler, primary energy savings are estimated at 16.9 TJ/year. The CHP plant has also contributed to significant reduction in the emissions: CO_2 - 2,310 tons/year; CO - emissions increased slightly; NO_X emissions reduced slightly; SO_X emissions reduced to zero, a reduction of 38 tons/year.

At 1993 prices, the investment cost was £358,000 with energy savings of £ 83,000 annually for a payback period of 4.3 years.

6.6 Process Integration

The aim was to optimise energy use by integrating supplies of an existing and a new brewery in Netherlands. Optimising heat transfer reduced evaporation. To cope with irregularities in supply and demand of heat, recovered heat was buffered in tanks.

Heat recovered is applied at the wort cooking. The wort, containing vapour, is condensed in a special condenser. The flash steam of the condensate is added to the wort vapour and condensed. This reduces evaporation losses from the wort vapour condenser and condensate is released at 95°C. A heat exchanger cools the cooked wort from 99°C to 9°C. With the secondary heat of the applied heat exchangers, water can be heated to 85-95° C.

In this project, integration of existing techniques such as vapour condensers, stratification tanks and wort preheating are combined to form a flexible system by which recovered heat can be used optimally. The heat storage capacity of the buffering tanks is dimensioned to cover the time between two brewing periods. Buffered heat is used for preheating the wort, and for filtering and bottling.

Primary energy was used for these purposes prior to the project. The results of the project are useful for medium and large-sized breweries.

Energy savings in natural gas were 41,700 m^3 per year for boiling wort and preheating of the wort from 75 to 92.5° C with heat from the wort-vapour-condensers instead of steam saved 1,130,000 m^3 gas equivalent. The extra electricity consumption of the pumps is 72,000 kWh/year (or 22,300 m^3 gas equivalents). The total energy savings are 1,150,000 m^3 gas equivalent/year.

Project cost: NLG 1,400,000; Subsidy: NLG 560,000; energy savings NLG 270,000/year (Gas price: NLG 0.237/m^3, Electricity price: NLG 0.11/kWh). Additional maintenance cost: NLG 14,000/year. Payback period : 5.5 years.

6.7 Variable Speed Drives on Secondary Refrigeration Pumps

A brewery in England installed an electronic variable speed drive (VSD) on a circulating pump in their secondary refrigeration circuit. This case study examines the merits of the installation and illustrates the energy savings and additional benefits achieved. The pump supply chilled alcohol (water and ethanol mix) for direct process chilling and to maintain the site's two cold rooms. The VSD was installed to regulate the supply of refrigerant to match demand. Installation was straightforward, requiring no changes to maintenance schedules, and has produced considerable energy savings. Potential users could be operators of secondary refrigeration pumps in the brewing, dairy and chemical industries.

The 75 kW secondary-circulation pump was originally operated at constant speed to produce a head of 2.09 bar. Average motor load was 55%, and control of flow was provided by a pressure-regulating valve, which diverted fluid to the bypass main to ensure constant system pressure. With the variable speed drive (VSD) installed, system pressure was reduced to 1.17 bar, whilst maintaining correct temperature and chilling duty. The VSD was positioned to allow it to be switched between two pumps, enabling phased installation and subsequent maintenance.

A dramatic reduction in average motor power of about 45% was achieved by introduction of the VSD. Previous pump inefficiency had led to transfer of heat to the refrigerant, increasing the chilling load. This was also eliminated by the VSD, giving total energy savings of 819 GJ/year.

Secondary pumping cost savings amounted to £5,638/year and refrigeration cost savings to £2,320/year, giving an annual cost of £7,958. Total project costs were £11,500, with a payback period of 1.45 years.

6.8 Oil Removers in Ammonia Cooling Systems

A brewery in Netherlands uses a central cooling system with ammonia as the coolant. Due to the large number of hours operating at full load, the system uses screw-type compressors. A disadvantage of these compressors is evaporation of oil applied as lubricant and sealant, which is transported into the cooling system by the ammonia flow. This oil contamination causes a film to settle inside the evaporators and condensers, decreasing heat transfer and causing fall in suction pressure, rise in condensation temperature and increase in operation time and electric energy consumption of the compressors.

Previously, oil was removed in two consecutive separators. The oil reclaimed from the ammonia flow was fed back to the system. However, due to high temperature of the ammonia (100°C), approximately 50 ppm of oil remained and entered the system.

A recent type of gas scrubber has been installed at the pressure side of the compressors. The oil concentration in the gas leaving the compressor has been reduced to less than 1 ppm. Not only does this lead to substantial energy savings, but also to an increase in the life span of the cooling system and a diminished need for maintenance.

Each of the four scrubbers consists of a packed column, the lower compartments of which are filled with liquid ammonia. Some of this liquid is injected into the hot gas entering the column. This causes the gas to cool down and the oil vapour to condensate. The oil and gas are separated at the top of the column, the heavier oil forming a thick layer underneath the gas. The gaseous ammonia is then led to the liquid ammonia at the bottom of the column and bubbles through, leaving behind the remaining oil.

The system lowers condensation temperature fall by 2°C, while suction temperature increases by 1.6°C. This leads to an overall improvement of the COP by 10%, decreasing annual energy consumption from 8,000,000 kWh to 7,660,00 kWh.

Investment cost; NLG 640,000; Annual cost savings: NLG 84,000; Labour NLG 10,000; Oil NLG 12,000; Waste disposal NLG 1,500; Maintenance NLG 5,000; Total NLG 112,500.The investment is paid back in slightly more than 5.5 years.

6.9 Inverter Speed Control to Reduce Power Consumption of Pumps

A brewery in Japan uses 3.3 kV induction motors for pumping and other applications. Many of these operate under highly variable loads and therefore waste a significant amount of power. VVVF (variable voltage, variable frequency) inverters allow pump motor speed to be continuously varied to meet load demand. For this project, five motors were selected to demonstrate the economic benefits of inverter installation and to assess operational difficulties. The five pumps featured a long running time, high power consumption and large load fluctuations, with the pressure and flow controlled by valves, dampers.

VVVF inverters control rotation of three-phase induction motors by varying frequency. In a pump, rotation speed is directly related to output volume and pressure as well as power consumption. Varying motor speed to meet changing demands in output volume and/or pressure reduces overall power consumption of the pump. During the demonstration period high-frequency noise from the inverter caused interference in photoelectric switches and industrial televisions in the factory.

The test demonstrated that the five pumps saved 709 MWh/year. These results were within 10% of the predicted values.

Assuming a unit price of ¥ 0.0148/kWh, the total savings amount to ¥10,550. The total costs for the installed group of inverters was ¥20,300. The simple payback period is approximately two years.

6.10 Bakery to Brewery Waste Heat Recovery System

A bakery and brewery, situated adjacent to each other, have worked together to install and implement an air-to-water heat recovery system that provides thousands of gallons of hot water for daily use in both plants. The bakery, the sole purchaser of the equipment, is responsible for maintenance and sells hot water to the brewery. The system consists of an air-to-water heat exchanger installed in the exhaust stack of the ovens, a feed pump, a circulating pump, and a 2,800 gallon water tank, a thermostat and insulated piping. The brewery's requirement of 20,000 gallons/month hot water for brewing, cleaning and sanitation purposes, and an additional 15,000 gallons/month for the bakery's cleanup and sanitation are provided by the system. This saves both companies the cost of installing boiler and purchasing energy to heat water. The total cost to the brewing company amounted to installing and insulating the pipe run within the brewery. This project demonstrates the energy and capital savings when adjacent businesses in industrial settings work co-operatively. While the system was not economically attractive to the bakery alone, the inclusion of the brewery made it affordable to both. The commitment to the system was made in the brewery's planning stage before installation of a traditional boiler system, after which it would have had little incentive to participate.

The bakery's savings from this system amount to USD 4,144 per month. Coupled with a USD 380 monthly payment from the brewery, this gives a payback period of less than three years. Costs for the project were USD 17,710.

6.11 Energy Waste Reduction

A brewery in the United States has cut refrigeration electricity use by more than 3%, without investing in new hardware. The brewery has made a series of small changes to the compressed control program to eliminate waste. As a result of the change, the brewery has reduced annual electricity use by 422 MWh and is saving $31,600 a year. This implies lower carbon dioxide emissions by 443 tons.

The refrigeration plant supplies brine at -10°C, which is pumped around the brewery to chill the beer during various stages of production. The chilling loads vary, requiring different combinations of compressors to run.

In examining compressor operation, it was found that the last compressor operating in the sequence at any time behaved as if it were running at low load, even when it was not. In this mode of operation, the compressor bypassed compressed refrigerant gas from the discharge line to the compressor's intake. The new control program limited this inefficient practice by allowing actual operating conditions to determine machine operation. The brewery has paid particular attention to energy efficiency improvements in its centralised refrigeration plant because refrigeration is the largest user of electricity on the site. Design and commissioning work to change compressor control programs cost about $10,000 in staff time. No new equipment was installed.

The brewery has identified additional improvements to extend the life of its refrigeration equipment, including changes to brine pipes, cooling tower upgrade and elimination of CFC use.

Project cost	:	No Capital cost; about $10,000 in staff time
Savings	:	$31,600 a year
CO_2 Emission reduction	:	443 tons per annum

6.12 Saving in Cooling System

The central cooling system at a brewery used to consume 15,000 MWh a year. The system comprises of three subsystems, each with their own temperature level: a 0°C system for cooling brewing water, a 5 °C system for removing fermentation heat, and a 10°C system for cooling alcohol water that replaces the refrigerant ammonia. Research revealed that cooling system compressors were running for long periods at fractional load with low efficiency. By computerising the central cooling system and optimising the control strategy, a 35% annual saving was achieved (5,500 MWh each year).

The temperature was no longer regulated separately by the subsystems controlled for the entire cooling system. This control system, instead of using more compressors at low capacity, employs fewer compressors at full load, so that their operating efficiency is greater.

The low-temperature levels are automatically adjusted to the required capacity. The number of pumps and cooling units are minimised without detracting from process conditions. All the circulation pumps at the brewing water coolers were removed, and at the condenser fans, the minimum condenser pressure was adjusted to the compressors in operation.

The payback period for the project is less than two years.

Section 7 - Checklist of Energy Savings Opportunities

Development of an energy conservation programme can provide savings by reduced energy use. However, it is economical to implement an energy conservation program only when savings can offset implementation cost over a period of time. Potential areas of conserving energy and a logical analysis of the methods or techniques of conservation would provide a systematic and disciplined approach to the entire conservation strategy as a sequel to the energy audit. Some established conservation trends are replacement, retrofit, process innovation, fuel conversion and co-generation.

The ABCs of Energy Savings can be used as a checklist to identify the areas of deficiency and adopt the right approach for energy savings.

A	B	C
Adjustable frequency drives *Ambient air reset controls* *Analysis of audit results*	*Balancing energy* *Blow-down controllers* *Break-even analysis*	*Co-generation* *Chiller efficiency optimisation* *Copper fins in cooling/heating*
D	E	F
Demand control *Delay monitoring and avoidance* *DDC management systems*	*Economiser controls* *Efficient equipment selection* *Energy audit and analysis*	*Fenestration techniques* *Filter loading control* *Fan efficiency optimisation*
G	H	I
Glazing systems for heat gain *Gas cooling* *General housekeeping*	*Heat energy tracking* *Heat recovery methods* *High efficiency criteria*	*Insulation* *Infiltration control* *Inspections*
J	K	L
Job-task analysis *Joint sealing and testing* *Justify retrofits*	*Kettle heat control* *Kwh and kw reduction* *Keg temperature control*	*Lighting* *Load calculation/ shedding* *Life-cycle cost analysis*
M	N	O
Maintenance *Metering* *Monitoring*	*Non conventional methods* *Novel technologies* *Natural gas use*	*Occupancy sensors* *Optimisation* *Over-rating avoidance*

P	Q	R
Peak demand shaving		*Retrofits*
Power factor corrections	*Quality*	*Return air systems*
Pay-back period		*Rate of return*
S	**T**	**U**
Solar energy	*Time of day*	*U-values*
Steam traps	*Thermostat settings*	*Utilities*
Selection criteria	*Temperature control*	*Utility meter close to site*
V	**W**	**X,Y,Z**
Variable air volume boxes	*Water conservation*	*XTMR losses*
Variable supply air setpoint	*Waste heat recovery*	*Yearly cost and savings*
Voltage selection	*Water treatment*	*Zone controls*

In addition to these basic checklists, the sections below deal with individual equipment to serve as a quick and handy reference, aimed primarily at shop floor personnel.

Burners

Supply correct burner nozzle for given turndown ratio
Adjust flame length to suit conditions.
Verify correct air pressure in LAP burners
Ensure no vapour/gases are present before light up.

Facilitate burners and damper for 13% carbon dioxide and light brown smoke
Underline importance of preventing oil leaks near burners
Establish air supply before oil supply, draining off cold air, and close oil line before shutting off air blower
Locate burners to ensure centring of flame with no impingement and correct oil temperature at burner tip

Power Factor Improvement

Install capacitors with phasitron control to modulate reactive power

Maintain peak load PF around 0.95 and use storage facility for peak hour requirements

Provide alarm system in maximum demand indicator

Restrict starting and stopping of high HP Motors simultaneously, staggeringworking and recess timings and avoiding idle running of machines

Operate and transfer high unit loads judiciously

Verify existing PF and redesign capacitors, selecting low dielectric loss capacitors

Ensure powerhouse is informed before switching on heavy loads.

Provide programmable timer based controls for exhaust fans

Flatten load curve and maintain a high load factor

Motors

Motor loss increases with voltage imbalance.

Avoid under-loading, as efficiency is low at 50% loading, with lower PF.

Install variable speed motor depending on process variations

Never use loose or excessively tight 'V' belts.

Try DC variable frequency drives instead of slip motors

Adopt proper maintenance practices to avoid friction losses.

Install automatic control to switch off idle motors

No size-load mismatch should occur, but choose highest possible motor speed

With high duty cycles, use high efficiency motors

Ensure replacement of rewound motors by standard motors

Low starting torque can be increased by soft starters with energy savers

Lubricate bearings regularly and provide proper lubrication and ventilation

Sub-Stations and Transformers

Adopt split bus system in substations to allow flexibility of operation
Distribute load to optimise loading after identifying under-loaded transformers
Have locations near load centre to minimise losses and improve tail end voltages
Ensure operation of identical transformers in parallel whenever required
Rotate cyclically and switch off idle transformers on primary side
Ensure transformers are switched off on holidays and power cuts

Try to provide a separate lighting transformer
Operate circuit breakers and disconnectors for transformers without fail

Select and use transformers with lower losses
Test tap positions of distribution transformers seasonally and re-adjust
Apply instrumentation for monitoring performance of individual transformers
Never select power transformers without OLTC and auto control.
Distribute and load bus bar sections parallel paths in sub stations equitably.

Distribution System

Add separate distribution switchboards for power and lighting circuits
Restrict LT distribution by increasing HT distribution
Draw balanced multiple circuits from secondary of distribution transformers

Operate ring main system for HT & LT systems for flexibility
Provide parallel paths and multiple cable runs to balance loads within +1%
Ensure cable carrying capacity in tune with requirements of machines
Replace old paper cables by new PVC/XLP cables
Ascertain equal distribution of loads on available parallel paths
Transfer and redistribute loads to avoid circuitous feeding
Install capacitors near load points or at sub-distribution board.

Motor Drive Installations

Never use oversized equipment
Gauge voltage at points of use and avoid voltage imbalance

Provide capacitors with higher voltage rating than supply voltage
Replace stalling high torque drives with hydraulic cylinders/ fluid couplings
Adhere to schedules and train operators for timing
Connect capacitors across motor terminals of heavy duty motors
Try to start motor preferably with a contactor for heavy duty Y-Δ installation
Install automatic controls and timers for optimum operation
Choose photocell control or long arm limit switch to shut off idle conveyors
Ensure squirrel cage motor reversing is withheld till speed has dropped to 60%

Lighting

Shun use of incandescent/tungsten filament lamps.
Weigh maintenance requirements and clean luminaries, ceilings, walls regularly
Install local switching for control of light fixtures and dimmer controls for flexibility
Try to locate workstations requiring most illumination near windows
Consider photocells and time clocks for turning exterior lights on and off.
Have translucent roofing sheets and maximise day light use

Operate electronic ballast of good make instead of conventional choke
Facilitate localised or task lighting consume less energy than general lighting
Favour selective switching of luminaires

Lower tap of isolating transformer to separate lighting load
Isolate lighting and ceiling fan circuit
Gauge surrounding décor and paint walls accordingly
Have fluorescent lamps in stairways, corridors, toilets and task areas
Try to use voltage controllers alternatively for discharge luminaires
Stagger 3-ϕ loading from poles and use 4-core cable for street lighting and

Refrigeration

Clean filters, heat exchangers and ducts regularly
Load freezers immediately after receipt of product
Eliminate unnecessary exhaust hoods and roof ventilators
Avoid artificial cooling where not needed
Never open doors unnecessarily and maintain temperatures with no infiltration

Control moisture sources to reduce defrost cycling
Hold routine checks for air inlets and seals for oil leaks
Identify excessive demand and components with low efficiency
Lessen operating time in areas with varying occupancy
Locate air paths such as to reduce airflow rates
Eliminate artificial ventilation where air quality, noise, loads permit
Reduce display lighting on refrigerated cases

Provide automatic shut off for fans on cooling towers and time switches
Improve controls on refrigeration system
Position thermostats and chilled water to higher temperatures
Explore two-stage cooling, with cooling tower water and then chiller water
Shut off air-conditioning in unoccupied areas

Compressed Air System

Substitute pneumatic instrumentation by electronic instrumentation
Test system availability and check logs periodically
Operate solenoid cut off valves in the air system
Provide extra air receivers and reduce delivery pressure where possible

Lubricate all pneumatic equipment properly
Ensure operation of pneumatic equipment at recommended pressure
Assess lubricating oil consumption, misalignment, debris and damages
Keep compressor valves and nozzles in good condition
Allow one small compressor handle load variation, with rest at full load
Gauge using hot compressed air for heat recovery and regenerative air dryers using heat of compression
Ensure minimal 'No-load' operation

Optimise automatic electronic moisture drain trap timings
Facilitate delay timers to limit number of motor starts

Clean cooling towers, fouled inter-coolers and air inlet filters regularly
Operate blow guns for clearing off swarf or moisture at low pressure
Monitor pressure drop by installing manometers across filter
Provide control by inter-linking water temperature and fan operation
Retrofit modern speed regulation controllers in big compressors
Ensure air intake is not warm and humid
Support installation of solenoid valves in the cycle punch press blow-off nozzles
Substitute two-stage or multistage compressor for large single stage ones
Ensure FAD and no-load tests are carried out periodically
Discourage misuse of air

Avoid oversized compressors and screw compressors at partial loads as efficiency is low
Inspect manual drains, pH of inter-cooler condensate for acidity and leakage
Replace V belts with flat belts and periodically adjust tension in drive belts

In conclusion, although a summary of the conservation opportunities has been discussed in Chapter V, only a detailed energy audit can examine specific plants for opportunities.

Section 8 - Energy Audit Approach and Methodology

8.1 Preliminary Energy Audit (PEA)

PEA is a preliminary data gathering and analysis effort in two parts: (a) the energy management audit, wherein the auditor acquaints himself with investment decisions and criteria referencing energy conservation projects and (b) the technical energy audit using available data.

The energy auditor relies on his experience to gather all relevant written, oral or visual information that can lead to a quick analysis of the existing energy situation. It focuses on the identification of obvious sources of possible improvement in energy use, such as missing insulation, steam and compressed air leaks, inoperative instrumentation and superfluous operation. The typical output of a PEA is a set of recommendations for immediate low-cost actions and, usually, a recommendation for a detailed energy audit.

8.2 Detailed Energy Audit (DEA)

This is a measured survey followed by a plant energy analysis. Sophisticated instruments, such as flow meters, psychrometers, flue gas analysers and infrared scanners are used to enable the auditor to compute efficiency and balances during typical equipment operation. The tests performed and instruments required depend on the type of facility, the objective, scope and level of handling of the energy management programme. The tests conducted include combustion efficiency tests, measurement of temperature and airflow of major fuel-using equipment, determination of power factor degradation caused by various pieces of electrical equipment and testing of process systems for operation within specification.

After obtaining the results, the auditor validates them using preliminary computation and existing support materials such as tables and charts. Then, he builds energy and mass balances, first for each major piece of equipment tested, and then, for the plant as a whole. From such balances, he can determine the energy efficiency of each equipment and scope for possible improvement in efficiency, with costs and benefits of selected options for each opportunity. In some cases, he is unable to recommend a specific investment because of its magnitude or the associated risk. In such a case, he may recommend specific feasibility studies such as boiler replacement, furnace modification, steam system replacement and process changes. The detailed report presents the auditor's recommendations, with costs, benefits and implementation aspects.

8.3 Steps in Energy Audit Programme

In an Energy Audit, detailed data are collected and analysed. Although sophisticated instruments are used, energy auditing is not an exact science. The auditor must use his knowledge and judgement to collect and interpret data suitably. The various steps in an energy audit programme are given below:

Step 1. Review energy management programme to date

The programmes are customarily reviewed with senior corporate staff. The auditor can decide what changes may be needed in the scope of the proposed detailed energy audit. If there is no formal programme, the auditor will try to understand why.

Step 2. Conduct preliminary energy audit

The preliminary energy audit (PEA) should be conducted after the review. The PEA consists essentially of gathering and analysing data. It uses available data only, without the use of sophisticated instruments. The results of the PEA depend on the ability and experience of the auditor. The output of the PEA is normally:

- *Development of energy consumption / cost data base for a facility*
- *Objective evaluation of plant condition*
- *Identification of major energy-consuming systems*
- *Understanding of company policies for energy-related projects*
- *Action plan for future energy auditing work*

The PEA generally has six steps.

1. ***Organise resources***
    - *Manpower / time frame*
    - *Instrumentation*

3. ***Identify data requirements***
    - *Data forms*

3. ***Collect data***

   a. ***Conduct informal interviews***

   - *Senior Management*
   - *Energy manager/co-ordinator*
   - *Plant engineer*
   - *Operations and production management and personnel*
   - *Administrative personnel*
   - *Financial manager*

   b. ***Conduct plant walkthrough/visual inspection***

   - *Material / energy flow through plant*
   - *Major functional departments*
   - *Any installed instrumentation, including utility meters*
   - *Energy report procedures*
   - *Production and operational reporting procedures*
   - *Conservation opportunities*

4. ***Analyse data***

   a. ***Develop database***

   - *Historical data for all energy suppliers*
   - *Time frame basis*
   - *Other related data*
   - *Process flow sheets*
   - *Energy - consuming equipment inventory*

   b. ***Evaluate data***

   - *Energy use - consumption, cost, and schedules*
   - *Energy consumption indices*
   - *Plant operations*
   - *Energy saving potential*
   - *Plant energy management programme*

5. ***Develop action plan***

   - *Conservation opportunities for immediate implementation*
   - *Projects for further study*
   - *Resources for detailed energy audit*
     - *systems for test*
     - *instrumentation - portable and fixed*
     - *manpower requirements*
     - *time frame*
   - *Refinement of corporate energy management programme*

6. Implementation

- *Implement identified low cost/no cost projects*
- *Perform Detailed Audit*

Step 3. Develop action plan, including detailed energy audit

On the basis of the review and the PEA, the energy auditor should develop an action plan, including a Detailed Energy Audit (DEA), considering:

- ➢ *Management of energy-related matters*
- ➢ *Monitoring and reporting considerations*
- ➢ *Relationships with manufacturers' representatives*
- ➢ *Availability of resources for implementing the action plan*

Step 4. Select scope of detailed energy audit

The next step is to determine the scope of DEA, in order to finalise resources requirement in the following areas:

- ➢ *Manpower: Manpower required for the DEA should be selected, on the basis of the review of the PEA, from internal or external sources.*
- ➢ *Instrumentation: The DEA provides the basis for the quantitative analysis of the energy performance of the facility. To compile the operating data necessary to make this quantitative assessment, a variety of fixed and portable instrumentation is used.*
- ➢ *Testing procedures: There are standard testing procedures for evaluating equipment performance, which the auditor may use as guidelines. For example, BIS 8753 provides methods for calculating the combustion efficiency.*
- ➢ *Cost for conducting the DEA: This depends on the time required to complete the DEA, in other words, the size of the plant and the report preparation time. The use of sophisticated instrumentation and overheads also add on to the cost of the DEA.*

Step 5. Complete preparatory work

All instruments should be calibrated, serviced and/or repaired, additional instruments purchased and test measuring positions and connections completed. The auditor should make sure that the time selected for the audit does not conflict with the operation of the equipment to be tested or the plant in general. The testing date should also be representative of normal plant operation.

Step 6. Carry out detailed energy audit field work

The energy auditor can now conduct the fieldwork for the DEA, which comprises two main tasks:

The first task is to gather data to evaluate all energy aspects using the PEA as a starting point, expanding on it, to fill gaps and learn more about the plant operation.

The auditor usually interviews selected personnel, examines records, observes operations, monitors and checks conditions. This may involve repeated data collection and review.

The most important part of an energy audit consists of the preparation of energy and material balances, first for individual equipment operations and then, for the entire plant. Without such data, it is rarely possible to carry out quantitative analyses to identify potential energy savings. Instruments play a vital role in measuring, indicating and controlling process parameters to achieve energy efficiency.

The second task is to perform tests on selected equipment to evaluate its efficiency.

Step 7. Evaluate collected data

Based on the raw data generated, efficiency of various equipment is evaluated. This involves detailed calculation, using computers and at times, specially designed software.

Step 8. Identify conservation opportunities

The results of the evaluation can be used to identify the energy conservation opportunities:

- *Better operation and maintenance by low-cost housekeeping measures*
- *Recovery of waste energy*
- *Improvement in equipment efficiency*

- *Installation of advanced control systems*
- *Change of technology*

These low cost opportunities require little or no major capital investment and have immediate returns on investment. On a simple payback basis, they have paybacks of less than a year.

Capital-intensive measures require large investments. Simple payback periods are usually more than a year. The auditor should use payback period as a guideline, while making his list of recommendations. He should also keep in focus, the attitude of the management towards capital-intensive projects.

Step 9. Develop action plan of implementation

The auditor will probably not have the authority to implement the measures identified, especially if capital requirements are large. Instead, he will complete a report, which will present his findings, with a concrete and time-bound action plan.

It should usually be possible to implement some O&M measures immediately. However, capital intensive measures may require feasibility studies before decision can be made to implement them.

An action plan often includes a recommendation for self-financing. In a self-financing programme, O&M changes are implemented and the resulting cost benefits are invested directly in lower-cost capital-intensive measures to bring in more savings. Eventually, these savings are used to pay for the most capital-intensive measures.

Step 10. Continue to monitor energy use

Energy efficiency in a company cannot begin and end with the DEA. To sustain its energy efficiency, a company must continue to monitor its energy use.

The DEA report should recommend improvements to the existing monitoring and reporting procedures for energy use. Very few companies, if any, have an adequate system of monitoring procedures. Without such a system, it is hard to spot changes in consumption that result from increase or decrease in efficiency. Possible improvements that can be made to monitoring and reporting procedures include:

- *Upgrading of instrumentation*
- *Development of energy consumption indices*
- *Development of energy models*

Step 11. Refine overall energy management programme

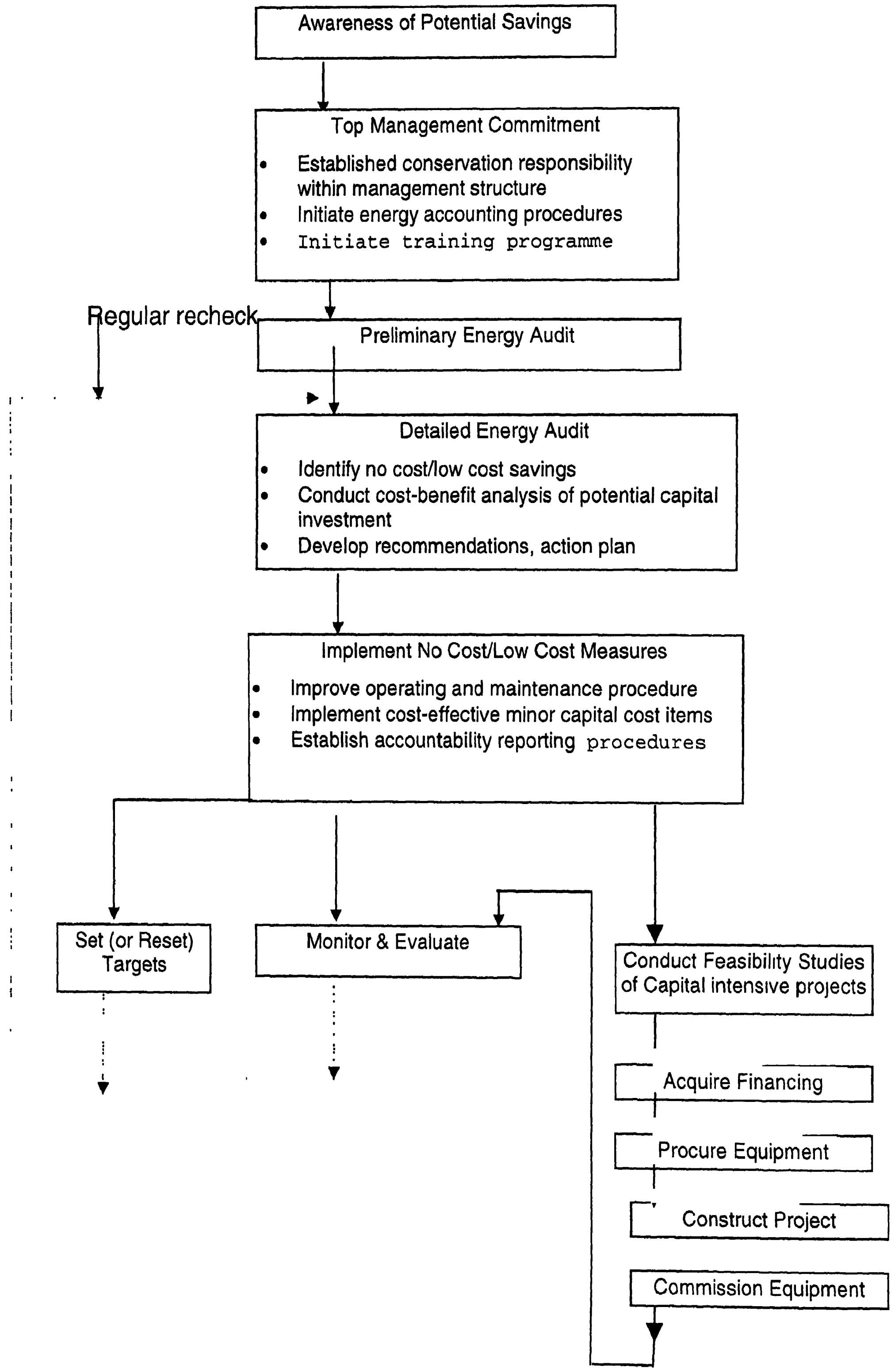
The major recommendations of the DEA should be refinements to the overall corporate energy management programme. Since energy affects so many aspects of operations, improvements in energy use cannot take place without commitment at the highest levels of management and a proper organisational framework. The management's perception of the state of energy use will determine the success of any energy management programme. Recommendations may include:

- *Appointing personnel to be responsible for energy*
- *Formally structuring a corporate energy management programme*
- *Training staff and employees in energy awareness*

In its efforts to maintain energy consumption within levels consistent with technological developments, the management may carry out regular energy audits to review the results of the improvement measures.

8.4 Energy Management Practice

- The energy management process in totality can be represented as below:


Awareness of Potential Savings
Top Management Commitment
• Established conservation responsibility within management structure
• Initiate energy accounting procedures
• Initiate training programme
Regular recheck
Preliminary Energy Audit
Detailed Energy Audit
• Identify no cost/low cost savings
• Conduct cost-benefit analysis of potential capital investment
• Develop recommendations, action plan
Implement No Cost/Low Cost Measures
• Improve operating and maintenance procedure
• Implement cost-effective minor capital cost items
• Establish accountability reporting procedures
Set (or Reset) Targets
Monitor & Evaluate
Conduct Feasibility Studies of Capital intensive projects
Acquire Financing
Procure Equipment
Construct Project
Commission Equipment

8.5 The Approach to Energy Management

The commitment of top management should be clearly demonstrated in policies and directives, with company decisions to control costs being clearly defined. Active participation in energy related activities by senior management is a vital step in this approach. Chart A presents this concept schematically. Practising energy management includes mandatory functions such as:

- *Identification of possibilities for further improvement*
- *Evaluation of these opportunities to prioritise them*
- *Implementation of conservation measures*
- *Continuous monitoring to sustain and further improve upon these measures*

8.6 Preliminary Analysis

In order to develop an energy management programme, it is necessary that the scope, extent of detail and the management cost and time expended should have some relation to the potential benefits of the programme. The cost incurred should not be more than the value of energy saved. The preliminary analysis should include with a preliminary analysis of parameters such as:

- *Consumption of various forms of energy*
- *Energy cost as percentage of production cost*
- *Major energy intensive equipment*
- *Potential savings and comparison with current profit*
- *Cost of additional metering possibly required to introduce the programme*
- *Efforts within existing framework to monitor energy consumption in different departments.*

Such a broad evaluation would give a perspective of the management time and cost value in relation to potential returns.

8.7 Energy Committee

Within the company, and particularly for larger industries, an Energy Committee would play a vital role of co-ordination between various departments. This may, for example, include senior managers, the Accountant and the Chief Engineer. Since accountability and authority go hand in hand, the Chairman should be a senior functionary, with authority to ensure that all resources are made available for necessary actions.

The Committee will be responsible for:

- *Developing the energy policy*
- *Managing the monitoring system*
- *Concurring upon and reviewing standards and targets*
- *Examining energy saving schemes*
- *Ensuring project implementation*
- *Any other matters relating to energy*

8.8 Energy Manager

A full-time energy manager may be appointed to implement the energy management programme, directly accountable to the energy committee. This would also be evidence of the management concern for and commitment to energy conservation. The energy manager should be an internal appointee, to ensure good practical knowledge of all aspects of operations, both technical and administrative.

Responsibility for Results

In general, organisation structures in the industry are based on three levels of authority with corresponding responsibilities towards efficiency of energy use.

Level 1: *Senior Management with responsibility for energy efficiency in the entire organisation, in relation to other resources, and in production of particular products.*

Level 2: *Middle Management with similar responsibilities, but limited to specific areas of the manufacturing process or divisions of the organisation.*

Level 3: *Process Operators, Foremen and Supervisors with responsibility for maintaining efficiency in a particular item of plant or part of a process.*

At all levels, regular reports on actual usage compared against norms and targets will be required in order to learn and correct deviations. The energy manager would provide these reports, analyse data, develop standards of performance and derive information for setting appropriate targets. He would also be responsible for *installation and operation of metering systems and the training of staff for the collection and analysis of data.*

8.9 Energy Management Process/Strategy

There are four distinct steps to the energy management process:

- *Defining energy accounting centres*
- *Measurement*
- *Analysis & Monitoring*
- *Targeting*

Energy Accounting Centres (EAC)

Along the energy flow paths of the plant, a series of energy accounting centres can provide the breakdown of energy input and output, for monitoring and achieving set targets. An EAC might comprise an individual equipment, a section or even a whole building. Each centre must have an individual responsible for both operational achievement and energy conservation, in order that his attention is focussed on the close relationship between the two aspects. He should have available pertinent information, on which to base judgements, decisions and actions to bring about improvements. Each EAC requires meters to measure the energy consumed over a period, and a means of measuring the production (or other specific variable) over the same period. As far as possible, EACs should correspond with the existing cost control centres.

Measurement

In order to be managed effectively, any resource must be measured accurately, to provide information to base decisions. Energy management depends on collection of relevant data, to judge current performance and plan for future improvements.

Analysis & Monitoring

Energy consumption and cost data can be collected and effectively used to analyse and evaluate performance. This involves regularly comparison of actual levels of consumption with a theoretical consumption defined by a set of internally based standards. These standards could be derived from a knowledge of the organisation's own capability, and then possibly further checked by reference to external norms. Difference between actual consumption and the corresponding *standards will reveal either improvements in energy efficiency or a fall-off in performance levels. The information gathered, thus provides quantified evidence of the success of implementation, or will indicate any failures, in order that remedial measures can be undertaken.*

The analysis should be a continuous process, and each line manager or plant operator must receive the energy throughput data regularly - on a weekly/ monthly basis - and promptly, so that deviations from standards can be quickly detected and corrected. In turn, line managers themselves must ensure that they respond rapidly to the information they receive. Well-designed reporting forms, expressed in readily understood terms, will be very helpful. Management information systems must ensure that the appropriate data and deviations reach the highest levels of authority. Just by the introduction of a monitoring system alone, many organisations have found that they could cut their energy consumption by up to ten percent.

Targeting

Once the energy management programme has identified and prioritised on the implementation of various measures, targets can be set for the implementation of change and the achievement of the predicted energy cost savings. The choice of targets will take account of current standards and the time frame for implementing measures. A organisation may wish to set a range of targets, taking note of the scope for improvement, the resources allowed by management to effect the improvement and the need to match accountability to the energy-accountable centres.

There are two principal methods of target setting. This first is the `top down' approach, a broad based generalised technique, which does not draw on a detailed analysis of the circumstances of the organisation, but may be based on experience in the sector as a whole.

The second `bottom up' method is based on a close knowledge of the energy requirements of different parts of an organisation. Both have their merits and can be chosen, depending on the efficacy in the given circumstances. Most organisations prefer the `bottom up' approach since it is, by its very nature, more closely tailored to there needs and hence more effective.

Correctly set targets have a strong motivational effect on the workforce. But it is important to avoid either impossible or too easy targets, since these can provide counter productive.

Means of Getting Good Co-operation from Personnel

a. Education

A well-designed familiarisation programme should convince employees of the need for good standards of housekeeping and energy awareness. They should appreciate that it is in their best interests to avoid unnecessary and excessive use of energy. Energy savings add directly to profit. However, it is important to emphasise that sacrifices are not being sought, nor are the employees expected to work in less than satisfactory conditions. Early results are unlikely to be sustained ndefinitely. People do tend to slip back into former habits, but the right climate can be established for introducing more complex and lasting measures gradually.

b. Awareness and information sharing

In most plants, employees have little or no idea of the amount of energy consumed within their plant, their section and even the equipment operated by them. In such a situation, what is required is awareness - which can be possible only by information, in the form of comparisons of historical trends, goals for overall energy use, energy intensity, in physical and monetary terms; checklists for each manufacturing operation outlining routine housekeeping measures, audio-visual presentations and literature.

Information must be presented in a manner that facilitates comprehension. If the information is too technical, theoretical, sketchy or dull, it is likely to be ignored or not understood. Terminology should be familiar to the daily life of the employees. For example, a sign saying, " stop steam leaks" will not be as effective as a sign saying " A quarter inch diameter steam leak costs Rs. 30,000/- per month".

Training is also an important means of both informing and involving people at all levels in an energy management programme. For operating personnel, training is required in practicalities of energy saving. This could be integrated into the organisation's other training programmes.

c. Motivation

Motivation is based on involvement, commitment and a sense of personal accountability. Top management must visibly demonstrate their attitude, originate the programme, generate and maintain the momentum.

Operators and maintenance staff should be involved actively, as they are ultimately responsible for execution. They are often in a better position to recommend areas for improvement. The most effective way of involving them is by simply going out and talking to them regarding goals, achievements, problems and progress or lack of progress.

Supervisors and middle level management should be involved by being assigned responsibilities for implementing and monitoring activities and submitting performance reports to top management, and by getting them to interact and communicate with operators and maintenance stand on progress and problems. If possible, energy management activities should be made a part of each supervisor's performance or job standard.

d. Publicity

Publicity and promotion are essential to publicise the benefits to the company and the workforce. Some commonly used means could be:

1. *Articles or implemented ideas in company or plant paper.*
2. *Obtain local newspaper interest and coverage.*
3. *Posters and pamphlets*
4. *Letterheads with energy conservation messages and ideas*
5. *Plant-wide, high-visibility vehicles or equipment to carry signboards*
6. *Monthly posting of results for the plant and department*
7. *Direct interactions of plant energy manager and personnel.*
8. *Quarterly site reviews and walk-through of unit.*
9. *An agenda item on energy conservation included at staff meetings.*
10. *Material provided to first-line supervisors for employee discussion periods.*
11. *Quarterly meetings held in the plant for all unit representatives*
12. *An Energy Awareness Day is set aside in the plant twice a year*
13. *A Company energy logo developed and adopted.*

8.11 Key Tasks of Energy Management

Energy Data Collection and Analysis

- *Maintain records of all energy consumption in the plant*
- *Check the reading of all meters and sub-meters on a regular basis.*
- *Specify additional meters required to provide additional monitoring capability.*
- *Develop indices for specific energy consumption relative to production and maintain these indices on a monthly basis for all major production areas.*
- *Set performance standards for efficient operation of machinery and facilities.*

Energy Purchasing Supervision

- *Review utility and fuel bills; ensure proper and optimum tariff application*
- *Investigate and recommend fuel-switching opportunities*
- *Develop contingency plans in the event of supply interruptions or shortages.*
- *Work with individual departments to prepare annual energy cost budgets.*

Energy Conservation Project Evaluation

- *Develop ideas, working with in-house staff, vendors and consultants.*
- *Analyse economics to permit management evaluation of projects.*
- *Obtain management commitment of funds to implement projects.*
- *Re-evaluate projects in tune with growth of company*

Energy Project Implementation

- *Initiate equipment maintenance programmes for energy saving*
- *Supervise the implementation of conservation projects, including specification, requests for quotation, evaluation of offers, ordering of materials, construction/installation, training, start-up and final acceptance.*

Communications and Public Relations

- *Prepare reports to management, summarising costs and consumption*
- *Effectively communicate with all production and support departments*
- *Develop an awareness programme to encourage active participation*
- *Develop training programmes to upgrade knowledge and skills*
- *Publicise company commitment to energy conservation*

8.12 Checklist for Top Management

a. Inform line supervisors of:
- Economic reasons to conserve energy.
- Responsibility for implementing actions in areas of accountability.

b. Establish an energy committee consisting of:
- Representatives from each department in the plant
- A co-ordinator appointed by and reporting to management.

c. Provide committee with guidelines as to what is expected of it:
- Develop uniform record keeping, reporting and energy accounting.
- Research and develop ideas on ways to save energy.
- Communicate these ideas and suggestions.
- Suggest tough, but achievable, goals for energy saving.
- Develop ideas for enlisting employee support and participation.

d. Set goals in energy saving, revising it based on savings potential

e. Employ external assistance in making recommendations.

f. Emphasise management's focus on conservation activities.

Duties and Responsibilities of Energy Manager/Co-Ordinator

- *Generate interest in conservation and sustain it with new ideas and activities.*
- *Summarise purchases, stocks and consumption, review and report utilisation.*
- *Focus of departmental records of use, ensuring uniformity and consistency.*
- *Co-ordinate efforts of energy users and set challenging but realistic targets*
- *Advise on techniques and source guidance on specialised subjects.*
- *Identify areas that require detailed study and prioritise them.*
- *Maintain records of all in-depth studies and to review progress.*
- *Provide basic handbook of good energy practice for operations.*
- *Advise purchasing, planning, production and other functions*
- *Ensure that health and safety are not adversely affected.*
- *Liase within industry to exchange ideas, protecting confidential data*
- *Contact research organisations, manufacturers and professional bodies*
- *Remain up-to-date on national energy matters and advise senior management.*

8.13 Instrumentation for an Energy Audit

Thermal related measurements:

The most common parameter measured is temperature. All evaluations of the heat contents of a stream or the energy consumption of a process depend on the temperature at each point of the stream or in the process. The instruments commonly used for measuring temperature are:

- *Mercury/ Bimetallic thermometer*
- *Thermocouple and indicator*
- *Thermograph*
- *Data logger*
- *Pyrometer*
- *Hygrometer*

Mechanical related measurements:

Flow measuring instruments:

- *Vane anemometer*
- *Pitot tube*
- *Air flow meter*
- *Orifice meter*
- *Venturi meter*
- *Ultrasonic flow meter*

Pressure measuring instruments:

Ultrasonic Leak Detectors

Speed measuring instruments:

- *Tachometers (Contact and Non-Contact Type)*
- *Stroboscope*

Steam trap-testing instruments:

- *Industrial stethoscope*
- *Electronic trap tester*

Chemical related measurements

- *Fyrite kit (percentage* CO_2*/* O_2 *in the flue gas)*
- *Oxyliser (%* O_2*,* CO_2*, flue gas temperature and combustion efficiency)*
- *Flue gas analyser (%*O_2*,*CO_2*,flue gas temperature and combustion efficiency)*
- *Dragger (CO)*

Electrical related measurements:

- *Ammeter and Voltmeter*
- *Power factor meter*
- *Power analyser (A, V, pf, kW, kVA, Hz)*
- *Current recorder*
- *Multi-meter*

Lighting related measurements:

- *Lux meter*

Section 9 - Advanced Retrofits

There have been a number of innovative novel technologies/retrofits prevalent in the industry, many of which are aimed at energy conservation. However, due to certain constraints, these technologies/ retrofits have not yet permeated into the grassroots of the industry, despite their obvious benefits. An attempt has been made to document a few of these, with a brief idea of their investment cost and potential for energy savings.

9.1 Waste heat recovery system on DG Set

Principle of Operation

In DG sets, 30 to 40% of the input heat escapes to atmosphere through engine exhaust gases. By installing a fire or water tube heat exchanger, heat recovery is possible. Heat is recovered from the exhaust gases of the engine as hot water or low pressure steam (100 - 120^{0}C) in the shell and tube type. Sometimes plate heat exchangers are used. As a further improvement, the waste heat recovery unit is specially designed to combine a smoke and water tube, fitted in a highly conductive metal matrix.

Energy Savings Potential

Approx. 15-20% of the input heat to diesel generator set can be recovered by installing these waste heat recovery systems. Investment cost depends on the size of the equipment and application.

For 500 kVA DG Set WHR -unit cost Rs.6.0 lakh
For 750 kVA DG Set WHR unit cost Rs.8.0 lakh

Areas of Application

Diesel Generator sets

Supplier

The product is indigenously designed and developed by
M/s Unidyne Energy Environment Systems Pvt. Ltd.
1-A, Shubhangini Subway Road
Santa Cruz (West), Mumbai 400 005

9.2 Cooling Tower Energy Saving Systems CTENSAVER+

Principle of Operation

Cooling towers are normally designed considering the worst process and weather conditions, sometimes including future expansion parameters. This usually results in over capacity of cooling towers and hence, lower cooling water temperature than required. During such low temperature periods, the cooling tower fan continues to run, consuming unnecessary electrical energy. With the use of microprocessor CT-ENSAVER +, the cooling tower fan operates only when required. Apart from this, additional energy savings are also possible if the outlet cooling water temperature is optimised, which is again based on certain assumptions.

CTENSAVER+ can also hook-up the following features :-

- ✓ Alarm when inlet and outlet water temperature increases beyond pre-set (design) temperature for which maximum efficiency is obtained
- ✓ Easy identification of problem of cooling tower or process side could be diagnosed easily.
- ✓ Pre-determined on-off cycle for motor fan can be taken care.
- ✓ Temperature limit could be taken care for safety limits of non-metallic part made of FRP and PVC components.

Energy Saving Potential

During low ambient / low temperature period of winter months (4 months/year) energy savings of 15 % is possible.

Areas of Application

All types of industries where temperature of cooling water is important.

Supplier
Ensave Systems Private Limited
3 Anand Shopping Center
Second Floor
Bhattha Paldi
Ahmedabad 380 007

9.3 Energy Saver for Air Conditioner - Conquest

Principle of operation

Conquest is an energy management unit with a patented logic residing in its memory. It continuously analyses the on - off cycle as demanded by thermostat, and load conditions. Based on the analyses and its predictive intelligence, the run time of the system is optimally controlled by conquest thereby reducing the power consumption.

Features

- ✓ Principle of Optimal stops
- ✓ Computerized intelligence executes a memory based timing of cycles.
- ✓ Works with any thermostatically controlled appliance.
- ✓ Compact Unit
- ✓ Simple installation
- ✓ Power on and savings indicator

Areas of application

Conquest Energy Savers can be used for Air-Conditioners, Refrigerating Systems, Water Coolers, Heaters, HVAC Systems, Heat Pumps etc., after studying the on-off cycle and also load conditions.

Supplier

Bharat Electronics Limited, Jalahalli Post, Bangalore 560013

9.4 Voltage Control Devices

The main supply voltage at the time and characteristics of the ballast dictates the wattage consumed by a discharge lamps. However use of an inductive impedance across the circuit to reduce the current could lead to energy saving but ensuring that any reduction in voltage does not affect the system even in case of low voltage conditions. Thus operating at optimum voltage levels (-10% of design value of system) using lighting transformers.

Energy Saving Potential : 15- 20 % in lighting energy consumption is possible.

Areas of Applications

The energy saving device is a proven product already operating in lighting circuits of numerous industries like textile, Paper, Cement, Engineering, Chemicals, Pharmaceuticals, Breweries, Steel, Rubber, Food, Railways, Mines, Defense, Ordinance, Plastics etc.

Suppliers

Beblec (India) Ltd
126 Sipcot Complex
Hosur 635126 Tamil Nadu
Phone: 04344 76358/76958/76959 Fax: 04344 76359

Electronics India
238/A, 10th Main Road,
Nagendra Block,
BSK II Stage, Bangalore 560 050

9.5 Energy Efficient System of Using Air Compressors

Principle of operation:

More often, the air compressors are not used in the optimal way. The compressor units are usually switched on and normally operate through all the working shifts. If there are three shifts of working, the compressor units are pressed into service almost without any switching off. Such operations render the system more energy inefficient and also may result in excessive wear and tear of the units.

The proposed compressor monitoring and control system would consist of the following features.

(i) Energy efficiency compressors to be base loaded.
(ii) Sequential switching on and off.
(iii) Close monitoring of system by P.L.C.
(iv) Serial port for computer.

Energy savings are due to:

1. Selection of high efficiency compressors for continuous operation (or higher number of hours of operation).
2. Minimising the no load running of the compressors

For a typical case of a bank of five compressors having efficiencies of 60-85%, motor power off take of 100 kW and unloading period of 30%, the energy savings are estimated to be about 30,000 kWh per annum. This calculation is based on the assumption of 40% power consumption during unloading and about 7000 operating hours in a year.

Areas of Application :

All industrial units where air compressor banks are used. They may be working on 3 shift basis.

Supplier :

M/s. Mundewadi Engineers Services Pvt. Ltd.
"Bhooshan" 24, Gururaj Society, 137/4, Kothrud
Paud Road, Pune - 411 029
Phone # 342435

9.6 VSD for Motors

Principle of Operation

This is control technique where in AC digital drive used for the specific variable torque demands of fan and pump loads against the current industry practice of employing commercially available over-rated constant torque machine control.

Areas of Application

Fans & Pumps are ideal applications since they, by far form the most common applications to be found in any manufacturing plant. Also they are invariably used in uncontrolled fashion with mechanical means of flow controls e.g., through vanes, Dampers & throttles. These can find application in other areas like compressors, cranes, hoists, etc.

Energy Saving Potential varies with application and variable load / torque requirement

Known Suppliers
Control Techniques India Ltd
117- B . Developed Flats
Industrial Estate Perungudi, Chennai 600 096
Phone: 044 4961123/4961130/4961083
Fax : 044 4961602

Asea Brown Boveri Ltd.
Sona Towers, 71, Miller Road, Bangalore 560 052

Kirloskar Electric Co. Ltd.
Unit IV, Belawadi Indl. Area, Mysore 570 005

Siemens Limited
Jyothi Mahal, III Floor, St. Mark's Road,
Bangalore 560 001

Allen Bradley Ltd.
C-11, Site-4, Industrial Area Shahabad 201 010

9.7 Auto-Drain valve (Compressed air condensate discharge)

Principle of operation

Compressed air condensate is collected in a container of drain valve. So that the capacative level sensor signals at the maximum point, the solenoid valve is then energised, closing the pilot supply line and allowing venting of the air above the valve diaphragm. The diaphragm lifts off the valve seat and the pressure in the housing forces the condensate into the discharge pipe. The electronic system of the auto-drain valve, condensate drain now calculates the discharge rate to the exact maximum valve opening time. The valve will again be fully closed and leak proof before any compressed air can escape.

Energy Saving Potential

Energy saving depends on the amount of condensate from receiver. Depending upon variation in humidity and amount of time present condensate valves opened for condensate removal, present air leakage from drain valve energy savings will vary.

Areas of Application

Compressed air receivers

Suppliers

Pace Equipment Pvt. Ltd
27 Q&R. Laxmi Industrial Estate
New link Road, Andheri (West)
Mumbai –400 053
Tel : 022-626 5239
Fax : 022-620 2557

Trident Corporation
42-A, Mamal Thottam, Ganapathy
Coimbatore, Tamil Nadu 641 006
Tel : 0422-530527,531947
Fax : 0422-532155

Section 10 - Economic Analysis of Investments for Energy Conservation

When any conservation opportunities are to be implemented, most measures do not require investments. However, it is possible that an investment, marginal or substantial, is sometimes incurred for specific energy saving opportunities. And, transferring the implementation from paper to actual practice involves making a decision - to invest or not to invest.

Usually, decisions are made regarding alternative solutions for utilisation of capital. At the outset, the decisions must not conflict with the objectives of the enterprise. These objectives can be constrained by social considerations or governmental regulations. They can be influenced partially by the owner's tastes or time required for implementation. However, the prime objective does not deviate from profit maximisation.

In order to aid the decision-makers, there are certain economic methodologies, which are followed. These are briefly discussed, although progressing beyond basic concepts would be beyond the scope of this manual.

All these methods are more or less reliable, depending on the accuracy of evaluation of the cash inflow and outflow, estimation of the discount rate (cost of capital) and prediction of the possible rate of increase of the energy price. Within these limitations, the most precise method is the Present Value Criterion, which compares the present value of all future after-tax cash inflow and outflow over a specified period of time to the present value of the cost of investment for the investment.

Although it may appear elementary, one has to recall here the fundamental rule of sunk costs, which says that in taking decisions about future investments, no role is played by past costs.

For example, when a new line of products is considered in a factory, the original book value of the existing old machinery already installed as irrelevant from the point of view of future cost evaluation. What is relevant is the present book value of the equipment, in the case that the old machinery can be sold or partially used to substitute the purchase of the new machinery. If the old machinery cannot be sold or used in the new production it is a "sunk cost" and has no relevance to the investment decision concerning the new machinery.

10.1 Present Value Criterion

The net present value (NPV) is defined as the difference between present worth of savings and cost of investment. The investment should be made if NPV is positive, and should be discarded if NPV is negative.

The present value method converts the money time series corresponding to the savings to an equivalent single amount at the date (year 0) when the decision to invest is to be taken. The present value criterion then compares this equivalent amount to the capital to be invested.

$$NPV = p \times \frac{1}{(1+r)^n}$$

Where p = future payments and income
r = pre-determined discount rate
n = number of years for which NPV is calculated

NPV indicates the return that the management can expect from the project at various discount rates. It can also be used to compare various projects with similar discount rates and risks, as well as compare them against a benchmark rate.

Internal Rate of Return (IRR) is the threshold rate at which the NPV is zero. It is the rate of return received for the project considering payments and income at regular intervals. This is commonly used for analysing investments in projects. A project is considered viable, if its IRR is greater than the interest rate offered by financial institutions for investing the capital with them that would be otherwise invested in the project.

10.2 Average Rate of Return Criterion

The average rate of return on investment criterion is not so precise as the present value criterion but it can provide a preliminary guide to investment decisions provided that the projected future annual cash savings can be assumed to remain constant.

For example, suppose the installation of a heat recovery device is considered. The heat recovery system installation costs Rs.10,00,000 and will last five years. The law permits a 20% annual linear depreciation factor. The new machine is expected to save Rs.3,00,000 in fuel costs annually.

10.3 Return on Investment (ROI)

The returns may be on the investment made or on a particular project or of the organisation as a whole.

Return on Investment (ROI) : Profit/Capital Employed

ROI is a combination of two ratios i.e., Profitability Ratio and Capital Turnover Ratio

Profitability ratio indicates the profitability of the organisation/investment/project while Capital Turnover Ratio indicates the efficiency with which the assets / investment are being employed. Greater the two ratios, higher will be the return on investment.

Generally the management analyses Profitability Ratios to take decisions pertaining to pricing policies, costs etc., while the Capital Turnover Ratio is analysed to take investment decisions.

The expected Return on Investment is generally the benchmark for investment decisions

10.4 Pay-Back Period Criterion

The Pay-back Period Criterion evaluates the time required to recover an initial investment via an annual net cash flow. It is defined as the investment cost divided by the cash flow. In the previous example of the heat recovery systems, the pay-back time in years is equal to 3.3 years.

Similar to the return on investment method, the pay-back criterion does not take into consideration the discount rate, the change in energy prices, nor the lifetime of the investment project. It has one advantage over ROI in that a precise indication of the annual benefit, namely the cash flow, is used instead of profits. However, both suffer from the difficult in justifying the threshold value beyond which no project should be considered.

In practice, investment projects with a pay-back period of three years or less almost always have a positive net present value. Thus the pay-back period is often used as a "filter", calculating NPV when the payback period is over three years and accepting the project when it is less.

10.5 Break-Even Parameters of Net Present Value

An important part of investment analysis, not to be confused with the pay-back period, is the calculation of the threshold value of a critical parameter of the net present value (NPV).

The threshold, or break-even value, is the value of a NPV parameter for NPV equal to zero. Any value beyond the break-even value will cause NPV to become positive and the investment acceptable.

Typical parameters studied in this manner include:

- The price of the service;
- The utilisation of the capacity of the investment;
- Various items of the cost of the project;
- The energy price increase, and
- Occasionally, the duration of the project.

When the latter is used as a parameter, the break-even time (in years) is a "true" pay-back period, where the discounted benefits begin to exceed the discounted costs.

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Appendices

Most of the processes of beer making have come down from generations. Beer production can be divided into malting and brewing, both of which are batch processes. Malting, using barley or any other cereal grain and water as raw materials moisturises and germinates the grains.

Brewing uses the malted barley or cereals, un-malted grains (adjuncts), hops, water and yeast for beer production. The differences in the types of beer depend on the raw materials used and the process. Basically, the beer differs with the yeast used. With the advent of new technology, the brewing industry has changed many traditional processes. A brewery usually has four sections:

- Brew House
- Fermentation and Maturation Section
- Bottling Section
- Utilities

This section of the report describes the processes and steps involved in beer making, to facilitate an understanding of the energy profile discussed subsequently. Fig. A gives a detailed flow diagram of the brewing processes.

A. Raw Materials

Water

To brew a volume of beer, 4 to 12 volumes of water may be required. Water is becoming an increasingly expensive and fast-depleting commodity. Large breweries use municipal water or borewell water. Water for brewing must be potable and is often modified by filtration and inclusion of salts and organic acids.

Malts

Malt is any cereal, usually barley, which has been germinated for a limited time. Germination stops when the grain is dried. In the malting house, enzymatic reactions are induced to break down the food polymers such as starch and protein in barley or cereal to produce fermentable sugars and other substances used in brewing. As the malt is friable, it is ground and extracted with warm water to give sweet "wort" or "extract".

Special malts are coloured malts with increased flavour, produced by heating normal malt. They are expensive and used in small quantities to give flavour and colour to certain beers. A cheaper alternative in some beers is roasted barley. Malt substitutes, in the form of malt extract and barley syrup, may be used in case of lack of malt extraction capacity.

Hops

Whole hops are kiln-dried cones of a plant. Other forms of hop include powdered hops (hammer milled whole hops), hop pellets (powdered hops packed as pellets), hop extracts as solvent extracts (hops extracted with organic solvents), liquid carbon dioxide and isomerised extracts. Isomerised extracts are used after the fermentation stage and cause post fermentation bitterness.

Yeast

Yeast is a living organism and strictly speaking, not a raw material. It is largely responsible for fermenting the beer. Two types of yeast are used in brewing:

- Ale Yeast - used for fermentation at temperatures greater than 15°C and large productions.
- Lager Yeast - used for fermentation at less than 17°C.

Adjuncts

These are additions used to supplement malt starch. These include cereals, syrups and sugars. Typical examples are flaked cereals, flours and grits. Typically, cane sugar has been considered on account of its widespread usage in Indian breweries.

B. Process Description

The four major processes involved in the industrial production of beer are:

1. Malting
2. Brewing
3. Fermentation
4. Conditioning

Malting Processes:

The various malting processes are:

Cleaning and Grading: The barley is subjected to a pre-cleaning process, where it is screened through a coarse sieve to eliminate large impurities. A fine sieve removes smaller impurities such as sand. During pre-cleaning, the barley is continuously removed by a recycled stream of air. It is sieve-graded according to its width.

Steeping: The barley is submerged in water for 2 to 3 days to activate germination. About 42-46% moisture content supports growth and biochemical alterations. The barley and steep water is loaded into the steep pool. A skimmer removes the foam on top. The process is carried out several times, changing the steep liquor. The steep temperature is maintained between 10 and 15°C and the liquor is drained once the moisture level of the grain is adequate.

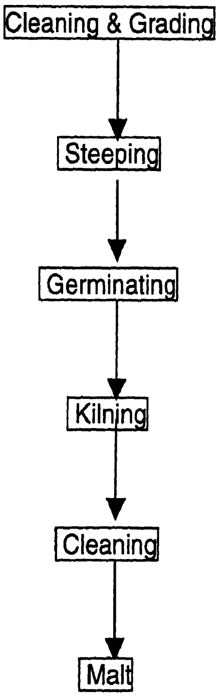


Fig. A : Malting Processes

Germination: is the conversion of the barley starch into malt (maltose) by the enzyme diastase. The intensity of the process is controlled by regulating the temperature at 14.5 - 16.5°C and moisture of the steeped grain. When germination has started, water is sparged over or wet air is passed through it to maintain the moisture level of the grains.

During germination, the temperature of the grain bed can be controlled by reducing its depth, to allow heat loss or increasing its thickness, if the temperature is too low.

Kilning: is a drying process using hot air to end germination and produce a dry, easily milled product. The moisture level is reduced from 42-46% to 5% for satisfactory storage. During this stage, the colour and aroma of the malt are determined.

Cleaning: The rootlets (culms) are easily separated from cured malt by agitation with beaters and screening. Sometimes, the malt is graded in three sizes for a better brewing process.

The finished malt is chalky and easily powdered, with increased enzyme power. Due to reduced moisture, it can be stored and powdered whenever required

C. Brewing Process:

The brewing process uses a mixture of malts and adjuncts called the grist. The grist is milled for better sugar extraction during mashing. After mashing, the juice or wort obtained is boiled to precipitate the proteins present. Hops are added during boiling to give a final flavour to the beer. Finally, the wort is cooled to avoid microbial infection, prior to fermentation.

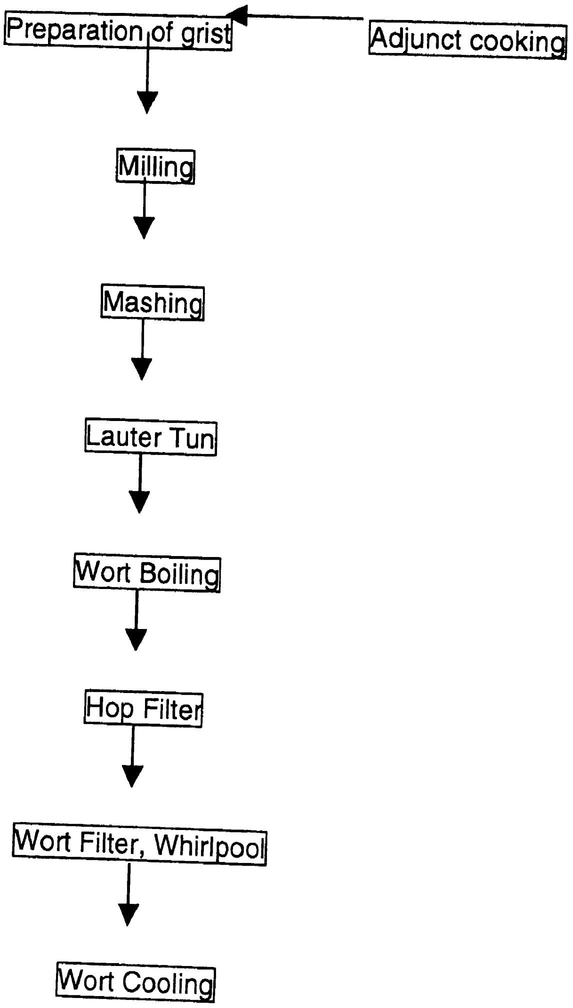


Fig. B : Brewing Processes

Preparation of the grist: Adjuncts are used to get cheaper extract, improve extract quality and for low colour beers. They are usually maize, rice, sorghum and wheat - all readily available. The preparation includes screening, washing, cooking and milling.

Milling: The malted barley and adjunct grains are milled with or without water. Wet milling increases moisture to 28-30%. The mixture of milled malt and adjuncts is called mash. The adjuncts are sometimes cooked before milling.

Mashing: begins when the mash is mixed with brewing water. Many interrelated chemical and physical changes occur simultaneously. The temperature is raised to 63°C and 74°C at pre-set time intervals, using steam as a heating agent. This process can take 1 to 3 hours, depending on the type of beer desired and the malts used. Design parameters for mashing equipment include accurate and complete control of the mash programme, minimal oxygen pick up, reduced shear stress from mash mixer and pump. Simple substances are rapidly dissolved and may be further degraded by enzymes. Enzymes also catalyse the hydrolysis of insoluble polymers to give soluble products.

Table 1 : Grist Composition for Beers (percentage of weight)

	Mild Ale	Bitter Ale	Lager	Malt Stout	Sweet Stout
Black malt	2	-	-	4	3.5
Pale-ale malt	-	76	-	93	-
Mild-ale malt	73	-	-	-	82
Lager malt	-	-	78	-	-
Crystal malt	-	4	2	-	-
Wheat	10	10	-	-	10
Maize	-	-	20	-	-
Sugar					
Inverted	15	-	-	-	-
Cane Sugar	-	10	-	-	-
Caramel	-	-	-	3	2
Syrup	-	-	-	-	2.5

The crushed mash is suspended in water and the reaction is allowed to occur at 21°C in the brew house. Another portion of malt is cooked separately with corn or rice. This mixture is then mixed with the malt mash. The two streams are mixed in a ratio such that the combined temperature is 71°C. At this temperature the diastase of the malt splits all the starch ($C_6H_{10}O_5$) of the grain into a sugar maltose ($C_{12}H_{22}O_{11}$) and glucose ($C_6H_{12}O_6$) by an enzymatic action. Thereafter, it is cooled quickly and transferred into a cellar for fermentation by adding yeast. The chemical reaction during fermentation occurring at 7 to 12°C under refrigeration, yields alcohol (C_2H_5OH) and CO_2 as:

$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_5OH + 4CO_2$$

Thus 1 kg of maltose yields 0.538 kg of ethyl alcohol and 0.415 kg of carbon dioxide. The heat released during this reaction is about 650 kJ/kg of maltose reacted.

Some enzymes may also dissolve the starch of un-malted adjuncts by converting to dextrose and maltose. Mashing can be by infusion, decoction or a combination of these methods. The liquor obtained is the sweet wort.

Infusion Mashing: The mashing tuns are insulated. Hot water between 71 and 82°C increases the efficiency of extraction by reducing the wort viscosity. About 70% of the water used during mashing is sparged over the mash. The wort temperature controls the mashing temperature.

Decoction mashing: The malt is less modified than in infusion mashing. The grains are also smaller. The mashing liquor is mixed with grist in a pre-mashing device. A large impeller at the base of the mashing tun completes the mixing. A part of the mashing mixture is separated from the mash, heated to boiling point and re-pumped into the mash tun. This process is carried out several times, increasing the overall temperature of the wort steep by steep. The usual decoction mashing processes are three-mash process, double decoction with one infusion steep and single decoction. A variety of mashing processes are used with a combination of infusion and decoction systems.

Lauter tuns: After mashing, the spent grains must be removed from the wort. Separation of the wort from the grain can take more than 2 hours. The sweet wort is separated on lauter tuns by sedimentation. Proper lauter tun design and operation yields the best sweet extract, reducing the unwanted malt constituents. The spent grains are sparged with water and pressed to recover the wort absorbed by the grains. Since the wort is hot at separation, there is a small loss of heat in the liquor retained by the spent grain.

Wort boiling: The sweet wort is boiled to precipitate the proteins (hot break) and to stop enzyme action. During boiling, some sugars and hops can be added -- hops are added to extract bitter resins (precursors of the bitter flavour of beer) and essential oils (characteristic of the aroma of beer). The hops can be fully or partially replaced by hop extracts. The brewing value is the alpha-acids fraction of the resins (the hops may contain 2 and 12% alpha-acids). An evaporation of 7 to 10% of the total volume is desirable. A boiling time of 90-120 minutes is normal. Steam is used as a heating agent in a jacketed vessel, usually made of copper or stainless steel. Evaporation rate, convectional movement and hot break formation are important kettle attributes. Within the brewhouse itself, the process of wort boiling is the most significant energy consumer. In recent years, maximum effort has been focused on this area to improve efficiency and thus, reduce energy consumption. Design considerations of the kettle must emphasise on energy efficiency.

Table 2 : Hops Rate in Brewing Industries

	Lager	Mild Ales	Pale Ales	Strong Ales
Hop kg/m^3 wort	1.4 - 2.1	2.1 - 3.5	3.5 - 4.2	5.6 - 9.1

Hop filters: If hops are used instead of their extracts, they must be removed by a screw conveyor. The spent hops are sparged with water and pressed to recover the wort.

Wort filters, whirlpool: The boiled wort is centrifuged or passed through a whirlpool tank to remove the hot break or trub by sedimentation, filtration, centrifugation or whirlpool. Some brewers prefer to cool the boiled wort first and then separate the wort. However, the usual practice is to separate the hot break before cooling and the cold break after cooling. Tank design and dimensions, tangential inlet proximity and inlet velocities are major considerations for a well designed whirlpool. Though most modern breweries use whirlpools to separate the hop trub, centrifuges are still used in a few of them.

Wort cooling: The cleared hopped wort is cooled in a plate heat exchanger. Some protein and tannin material oozes out of the solution as a fine coagulum or cold break. This can be removed completely by filtering the cooled wort to -5°C.

Fermentation:

The carbohydrates in the wort, glucose, fructose, sucrose and maltose are the main source of carbon and energy for the yeast. The nitrogen sources are the amino acids in the wort. The difference between bottom and top yeast is that, after fermentation, the bottom yeast tends to settle while the top yeast rises. Infusion mashed worts are fermented with top yeast, while the decoction and double mashed wort are usually fermented by bottom yeast. Lagering refers to the maturation and storage of the beer after fermentation. The various fermentation processes are:

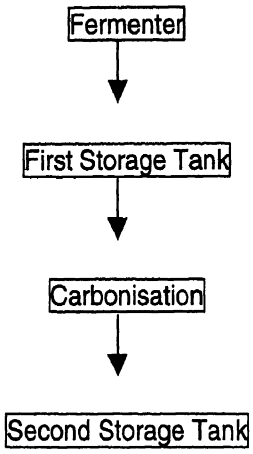


Fig C : Fermentation Processes

Pitching: The cooled wort is aerated to increase dissolved oxygen to 8 - 10mg/l to aid the yeast to grow. Pitching requires a thorough mixing of the wort and the yeast.

Fermentation: The yeast increases 5 to 12 times its original weight. As the yeast metabolism is fermentative, the carbohydrates are degraded to ethanol and carbon dioxide. The fermentation vessels may be open or closed. Fermentation takes place in open or closed-jacketed vessels, usually made of stainless steel, at 0 to 10°C for a period of six days, by circulating cold brine. The process is exothermic in nature. Carbon-dioxide is evolved, which is collected by a few breweries for carbonation. The specific gravity at the end of fermentation is about 2 (SG 1.067). The rooms where fermenters are kept are also maintained at 11 to 12°C.

Yeast from bottom fermentation is passed through an oscillating fine sieve and washed with cold water. In top fermentation, the yeast is collected by suction or using a conical collector. A sheet press filter is used for recovery. Continuous fermentation with a high concentration of yeast can be used. The yeast is separated from the beer by settling or centrifuging.

First storage tank, second fermentation: The beer is cooled to 2°C and stored. Some brewers add sugar or sweet wort to induce a second fermentation in ales. The carbon dioxide produced dissolves in the beer and hence the beer requires less carbonation. The yeast is removed by settling or centrifuging.

Carbonation: After lagering (maturation and storage), the beer is carbonated with carbon dioxide and conditioned at temperatures near 0°C to facilitate dissolution of the gas. If a second fermentation has been done, the carbonation stage can be eliminated or reduced.

Second storage tank: A final storage is undertaken prior to bottling the beer.

D. Beer conditioning:

Before being sold, the beer needs conditioning -- the beer is centrifuged, filtered and pasteurised and some conditioning agents are added to preserve it. The fermented beer is taken to lagers, where the yeast further metabolises some of the by-products, which it produced earlier. The beer is chilled to near freezing and held there for several days to weeks, depending on the desired quality. Many chemical processes take place in this time, to make a clean, tasty, homogeneous beer. Extended conditioning time naturally clarifies the beer. The final specific gravity at the end of saturation is about 1.6 (SG 1.067) with 2% carbon-dioxide. Pasteurisation is usually done when filling the beer in bottles. The various conditioning processes are:

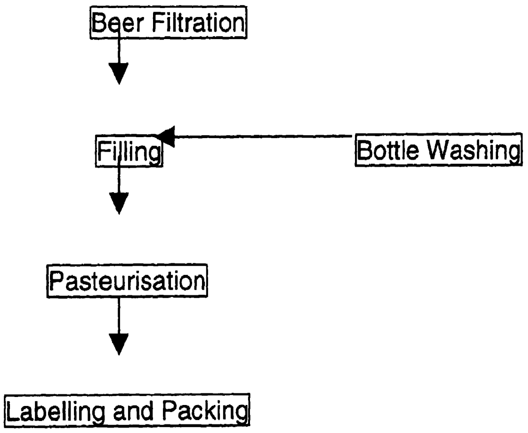


Fig. D : Conditioning Processes

Beer centrifugation and filtration: Before filling the bottles, cans, kegs or bulk tanks, the beer is filtered to eliminate any yeast or bacteria present and ensure microbiological stability. A first centrifugation unit is used to remove the cold break formed during storage. A Kieselguhr filtration unit usually carries out filtration. The filtration gives it shelf stability and colour. However, filtration to below one micron also strips some flavour and components of the beer.

Filling: is a mechanical procedure. Before filling, the bottles, kegs, or bulk tanks must be washed. The washers have a number of stages that include several rinses, soaking and final rinses at various temperatures.

Pasteurisation: After filling, the bottles are pasteurised to ensure that the beer is sterile -- a minimum time and temperature is required to destroy all possible biological contaminants. The process can be carried out before or after filling. If pasteurisation is before filling, the bottles must also be sterilised and the filling unit must be sterile. Usually, it is carried out after filling. Cans require a shorter pasteurisation sequence because of their superior heat conductivity. Pasteurisers use minimum water and steam provided they are balanced and run at full capacity. They should not be frequently stopped and started. Water level controls should work properly with all instruments correctly calibrated. A flash pasteurisation unit can replace conventional tunnel pasteurisation, as it requires less space, steam and coolant. If flash pasteurisation is carried out, filling conditions must be sterile.

Alpha-Acid These are a major component of the soff resins. When isomerised, these materials provide the main bitter compounds associated with beer. The alpha-acid content varies widely amongst hop varieties from levels of 3-4% w/w in aromatic type hops to levels of 10-14% in the bitter hops.

Aroma Much is spoken of the organoleptic quality and intensity of dried hop aroma. These arc again strong variety characteristics. There does appear to be a general relationship between the type and heaviness of a hop aroma and the flavour and aromatic properties of a resultant beer. However, this relationship can be obscured by the manner of using the hops. A skilled, comparative aromatic evaluation of samples of one variety can detect those samples that have been picked too early or too late, overdried or stewed. Moreover, a trained evaluation can select particularly favourable growths of a variety from within the normal range of aroma exhibited by that variety in a particular season.

Beta-Acid Another soff resin component, the beta-acid, is not bitter in the natural or isomerised form. Some of the oxidation products do provide bitterness, and the beta-acid can be chemically transformed into light-stable bittering forms.

Caryophyllene One of the four major components of the essential oils: Myrcene, Humulene and Farnesene being the other three. Between them the oils account for about 60-80% of the essential oil of most varieties. The amount of these constituents and particularly the ratios between them can be used as dear variety characteristics. These compounds are all highly volatile hydrocarbons; and during boiling of the wort, most, if not all of them, arc driven off and so contribute little to hop flavour and aroma in beer. Some of the oxidation products of these compounds, such as the Humulene, epoxides, arc thought to be positive contributors to beer flavour and hence sufficient ageing of aromatic hop varieties is necessary to allow these products to he formed.

Co-Humulone The alpha-acid exists in three analogous forms, humulone, ad-humulone and co-humulone; and the properties of these analogues vary markedly with variety. It is widely held that relatively high levels of co-humulone produce a harsh, unpleasant bitterness and have a negative impact on head retention. Although this belief is still being questioned, varieties with relatively low co-humulone levels arc still strongly favoured.

Cone Structure Certain physical properties of hop cones3 while relatively unimportant in the brewing process are strongly characteristic of a particular variety. For example, the cones of English fuggle are markedly square in cross section. Light loose cones are

much more prone to shatter during harvesting while heavy dense cones, like those of English Northdown pick beautifully as they roll well and hang together.

Disease Reaction Different varieties can display a wide range of reaction to various hop diseases. Of great importance in England is Verticillium Wilt and the fungal diseases Downy Mildew (caused by Psuedoparonospora humuli) and Powdery Mildew.

Drying Some varieties are more difficult to dry than others. Growers can adjust practices to accommodate these peculiarities but the more difficult a variety the more likely it is that mistakes will be made.

Farnesene One of the four major components of the essential oils: Myrcene, Humulene and Farnesene being the other three. Between them the oils account for about 60-80% of the essential oil of most varieties. The amount of these constituents and particularly the ratios between them, can be used as dear variety characteristics. These compounds are all highly volatile hydrocarbons; and during boiling of the wort, most, if not all of them, arc driven off and so contribute little to hop flavour and aroma in beer. Some of the oxidation products of these compounds, such as the Humulene, epoxides, arc thought to be positive contributors to beer flavour and hence sufficient ageing of aromatic hop varieties is necessary to allow these products to he formed.

General Trade Perception Over a number of years a hop variety will find a particular role or niche within the brewing industry and its particular properties will become well known and accepted. This general perception is helpful to brewers considering the use of a variety new to them.

Growth Habit Hop varieties vary widely in structural aspects such as general vigour, lateral (or side arm) length, and the overall bine structure. These characteristics can make a variety more or less easy to pick and handle.

Humulene One of the four major components of the essential oils: Myrcene, Humulene and Farnesene being the other three. Between them the oils account for about 60-80% of the essential oil of most varieties. The amount of these constituents and particularly the ratios between them, can be used as dear variety characteristics. These compounds are all highly volatile hydrocarbons; and during boiling of the wort, most, if not all of them, arc driven off and so contribute little to hop flavour and aroma in beer. Some of the oxidation products of these compounds, such as the Humulene, epoxides, are thought to be positive contributors to beer flavour and hence sufficient ageing of aromatic hop varieties is necessary to allow these products to he formed.

Lupulin Hop lupulin may vary in colour from pale yellow to an intense golden colour. It is not known if lupulin colour affects brewing performance but it is a fairly strong characteristic of a variety. It is certain that the bitter hops have much greater quantities of lupulin than the aromatic types.

Maturity This is a statement of the time in the hop harvest season at which the particular variety reaches optimal maturity. Harvesting in England occurs from about the end of August to the end of September. Of current English varieties, the aromatic types tend to be earlier maturing than the bitter type varieties.

Myrcene One of the four major components of the essential oils :Myrcene, Humulene and Farnesene being the other three. Between them the oils account for about 60-80% of the essential oil of most varieties. The amount of these constituents and particularly the ratios between them, can be used as dear variety characteristics. These compounds are all highly volatile hydrocarbons; and during boiling of the wort, most, if not all of them, arc driven off and so contribute little to hop flavour and aroma in beer. Some of the oxidation products of these compounds, such as the Humulene, epoxides, arc thought to be positive contributors to beer flavour and hence sufficient ageing of aromatic hop varieties is necessary to allow these products to he formed.

Packing Some varieties tend to shatter more than others when being packed. Growers can adjust practices to accommodate these peculiarities but the more difficult a variety the more likely it is that mistakes will be made.

Pedigree These are brief remarks about the ancestry of a variety. Modern varieties can often be traced back through two to three generations of crosses often involving other known hop varieties. It is important to note that the qualities of a hop variety are only partly determined by the genes it receives. Of at least equal importance is the selection for particular characteristics practised by the hop breeders.

Pickability This is another characteristic, which is of direct concern to both grower and brewer. If a hop is known to pick well, one can expect a good clean sample. If a hop is difficult to pick, one is more likely to see shattered cones and a higher proportion of leaf and stern in a sample.

Storageability Oxidation of alpha-acid removes its ability to be isomerised to the required bitter isomers. In comparable circumstances some varieties lose a greater proportion of their alpha-acid to oxidation than do others. Cold storage and anaerobic conditions can both delay oxidation, hut the innate property of a variety in this context is important in commerce. interestingly, some oxidation of essential oil components is necessary to produce compounds thought to be important in beer flavours so controlled ageing is important for hops required for both bittering and aromatic purposes.

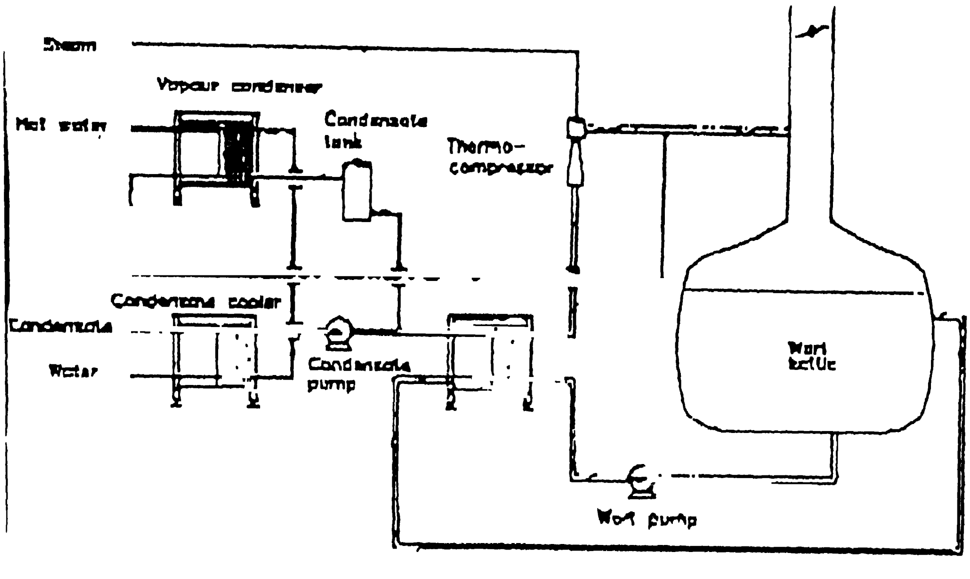
Total Oil This characteristic varies widely amongst seasons, varieties and growths from 0.5 mls to about 3.0 mls per 100 grams of hops. Whilst the soft resins are responsible for providing the bitterness of a beer, the quantity and composition of the essential oils are responsible for the amount and quality of hop flavour and aroma in beer. A brewer, when deciding on which varieties and how much to use, will always consider the hops' contribution to flavour and aroma as well as its bittering potential.

Yield This is the kilo dry weight of hops in zentners (1 zentner 50 kilos) normally produced by that variety in commercial production in England. On average, the aromatic types tend to be lower yielding and hence more highly priced than the bitter types. As with other crops, yields vary markedly from farm to farm and year to year. Hence, the range in yields can be quite wide.

Most breweries outline to accord a low priority to energy conservation. Over production of hot water, not only waste energy, but also has an impact on the environment, by discharge. Wort boiling accounts for almost half the thermal energy consumption of the brewery. As steam generation is often stretched to critical limits, wort boiling becomes a bottleneck in the brew-house. It is therefore important to examine this part of the process critically, to implement measures to improve efficiency and cost effectiveness, reduce wastage and meet statutory norms. Increased competition in the market implies production of quality brands at low costs, while complying with existing and projected environmental legislation. A co-operation between Alfa Laval and Entropie of France has seen the development of "Ejectotherm" a wort boiling system with energy recovery.

Ejectotherm is based on the principle of boiling the wort via a low temperature process. This is accomplished by using a specially designed wide-gap plate heat exchanger in combination with a thermal vapour compressor. A saving of almost 70% of live steam can be achieved, compared to conventional wort boiling. The system can be easily integrated into existing brew-house plant since it is supplied, mounted on a skid and designed for minimal on-site installation. For large breweries and special applications, bespoke systems can be provided. The principle of operation can be seen in Fig. A.

Fig. A : Flow Diagram of Ejectotherm Wort Boiling



The wort is first heated, using an existing heating system i.e., by the heat exchanger used for boiling or by dedicated wort pre-heater. The Ejectotherm begins when the wort starts to boil. Vapour from the wort surface is recovered and pumped into a liquid separator, where condensed droplets are removed, and then into the thermal vapour compressor, where the pressure is increased using medium or high pressure 'live' steam. The steam mixture is then passed through a plate heat exchanger to heat the wort circulating from the copper. The hot wort is then returned to the copper, below the liquid level, where it flashes off and starts a new cycle through the system. The vapour used for heating passes through a vapour condenser, which in tandem with a condensate cooler, is used to produce hot water which can be supplied anywhere in the brewery.

Concept

Evaporation naturally implies high energy costs. A suitable means to reduce these costs drastically is the use of mechanical vapour recompression. Waste heat in exhausted vapour can be recovered by boosting the vapour to a slightly higher pressure, using a mechanical compressor.

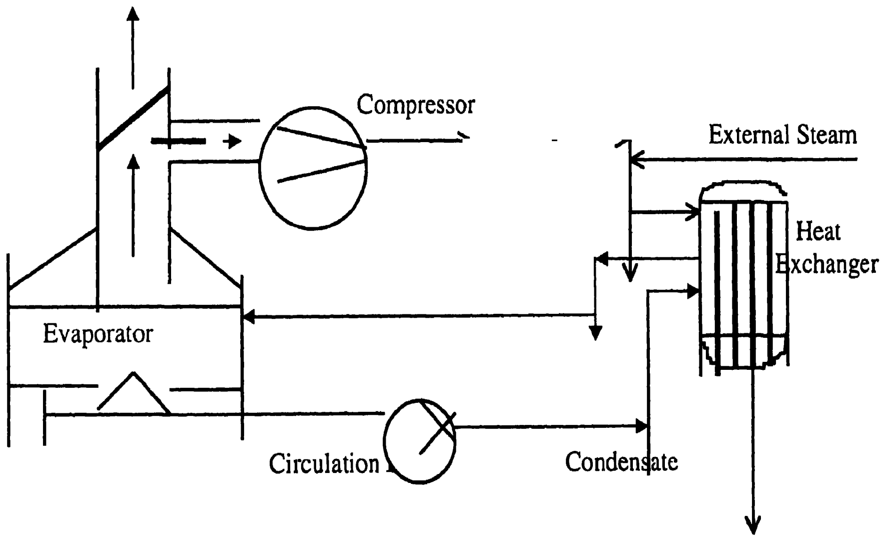
Vapours are compressed to a higher condensation pressure/temperature - as done by steam jet thermo-compressors for many years. As a general principle, however, a jet pump is capable of compressing part of the vapour only. The mechanical vapour recompressor on the other hand operates with the whole vapour flow, so that only small quantities of steam and/or cooling water are necessary for thermal balance and start-up of the evaporator. In the process, efficiency is also improved.

Process

Vapour compression is an open heat pump process where the compressed vapour is used as a medium of heating. The development of sufficiently sized external boilers was necessary to achieve low compression ratios. Vapour compression devices are widely used in many industrial sectors. Most are built as mechanical compression units. Almost every compression unit consists of a roots-compressor combined with an electric motor.

Prerequisites to achieve high-energy efficiency are to maintain the vapours to be compressed at atmospheric pressure and to limit the increase in pressure to a small value.

Schematic of Mechanical Vapour Recompression.



The figure shows the use of the Mechanical Vapour Recompression unit for evaporation of water from process liquid. The principle of operation is to mechanically compress water vapours at a lower pressure into higher-pressure steam. The diagram illustrates water from a boiling fluid in the large vessel being captured and compressed into steam by a compressor. The steam exchanges heat with the fluid in an external calendria. The fluid is kept in circulation by a pump. The calendria can be provided with external steam during start-up operation.

Additional factors to be considered while installing the MVR are:

- Consumption of the balance warm water
- Additional power consumption
- Possibility of using existing kettles whether those kettles can withstand the proposed system
- Space required

The investment could range between Rs. 4-8 million, depending on the type of process, capacity of the kettle and site-specific conditions.

The vessel is designed for a maximum operating pressure of 0.6 bar, corresponding to a temperature of 113°C with suitable controls and safety devices to avoid over-pressure conditions. The energy storage system is adopted to store the heat recovered from the vapours. The water, which can be heated up to 96°C with vapours, can be used for the mashing operations to reduce water usage. The investment for a heat exchanger unit and a storage vessel is not significant. A schematic is provided in Fig.A.

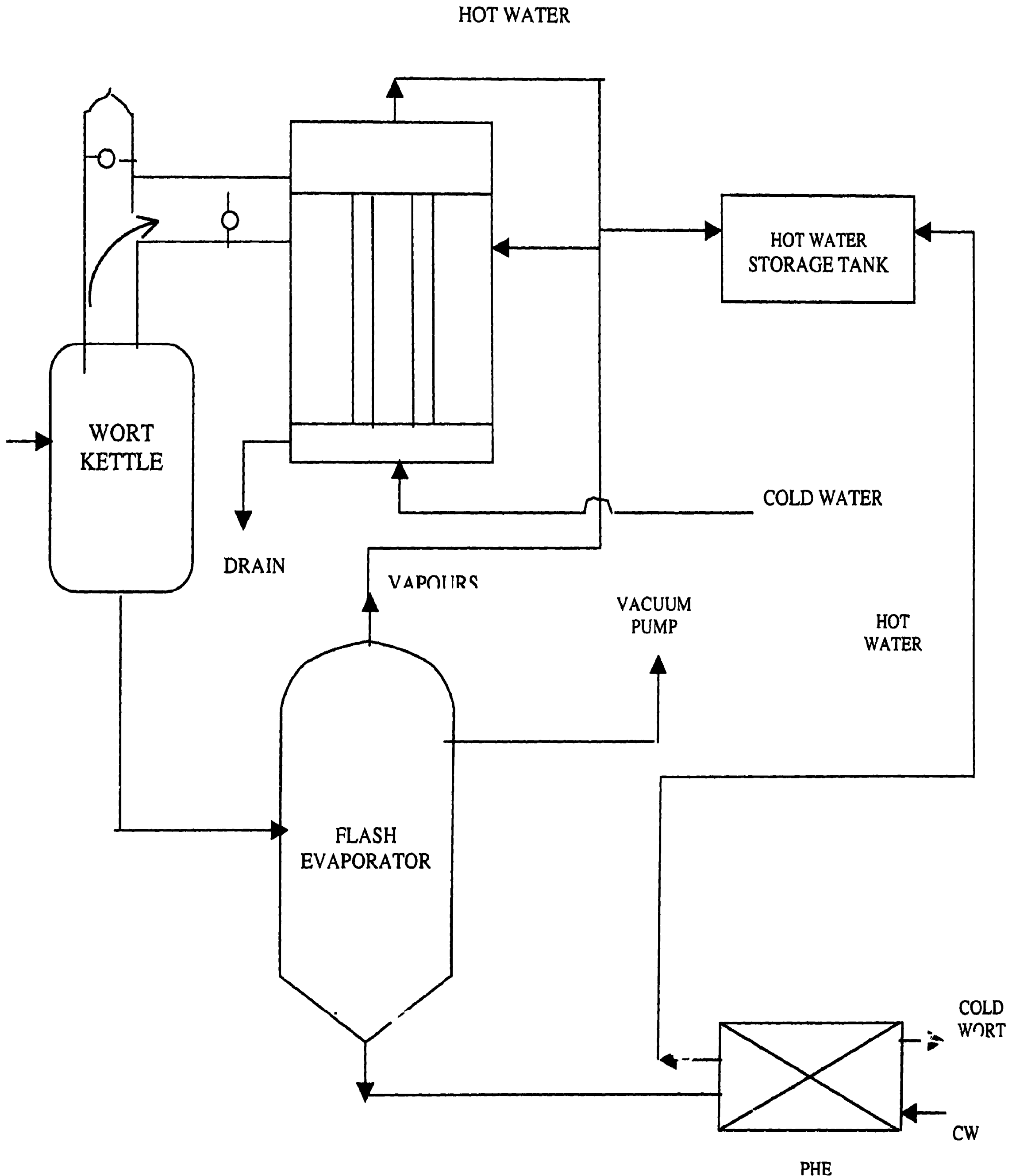


Fig.A : Flash Evaporation System with Heat Recovery from Vapour

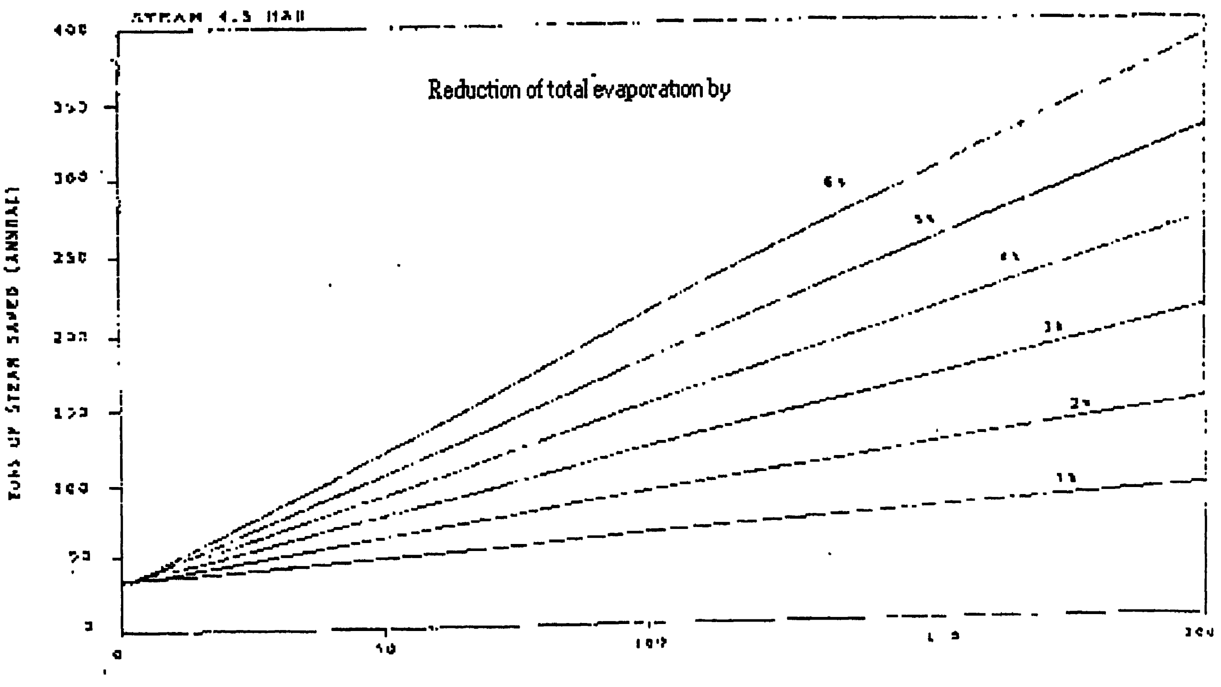


Fig. B : Steam Savings from Pressure Boiling

Up to 50 percent saving in primary energy can be achieved, when compared to conventional boiling. The steam required for boiling can be reduced by 7 kg/hl of finished wort. The savings for various evaporation rates in the kettle are depicted in Fig.B.

The absorption refrigeration machine is a water-chilling package that uses heat directly without a prime mover, thus utilising heating facilities on a full time, round-the- year basis. It can be installed anywhere, due to its compact size and vibration-free operation. It uses the cheapest, safest and most available of all refrigerants, ordinary tap water. Its absorbent is a simple salt.

Application

Absorption Refrigeration finds usage where:

- Low cost fuel is available
- Electricity rates are high
- Steam utilities are desirous of promoting summer loads
- Low pressure boiler capacity is largely unutilised during cooling season
- Waste steam is available
- Facilities are adequate for a conventional compression machine.

The absorption machine uses only 2 -9% of the electric power required by the vapour compression equipment. It may be applied in conjunction with gas engines or turbines and centrifugal machines as combination systems.

Description

The absorption machine uses water as a refrigerant and a salt solution such as lithium bromide as an absorbent. It consists of the following major components:

a) ***Evaporator Section :*** where the chilled water is cooled by the evaporation of the refrigerant, sprayed over chilled water tubes.

b) ***Absorber Section :*** where evaporated water vapour is absorbed. The heat of absorption is removed by condenser water circulated through this section.

c) ***Generator Section :*** where heat is added in the form of steam or hot water to boil off the refrigerant from the absorbent to re-concentrate the solution.

d) ***Condenser Section :*** where water vapour produced in the generator is condensed by condenser water circulated through this section.

e) ***Evaporator Pump :*** which pumps the refrigerant over the tube bundle in the evaporator section.

f) ***Solution Pump :*** which pumps the salt solution to the generator and also to the spray header in the absorber.

g) ***Heat Exchanger :*** where the dilute solution being pumped to the generator from the absorber is heated by the hot concentrated solution which is returned to the absorber.

h) ***Purge Unit :*** which is used to remove non-condensables from the machine and maintain a low pressure in the machine.

Fig. A Standard Vapour Absorption Refrigeration System

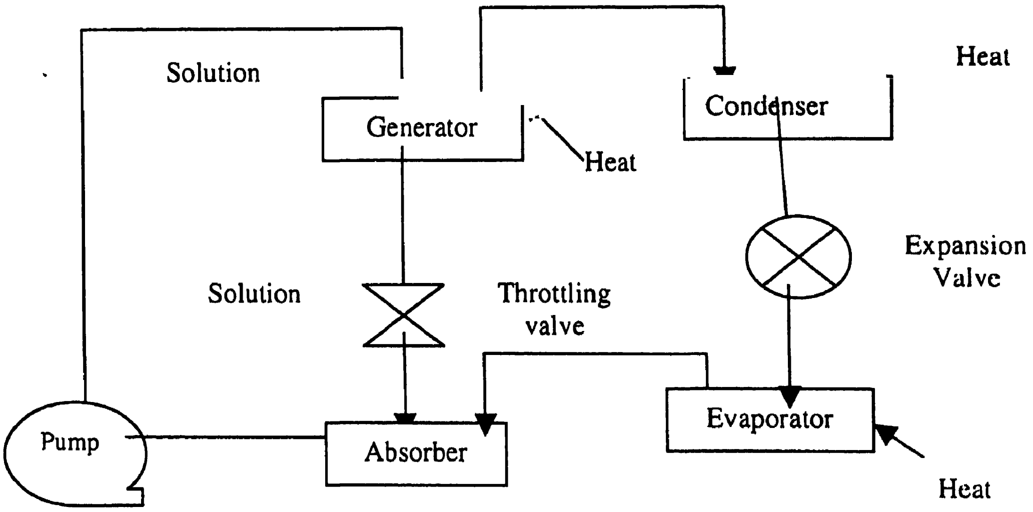


Figure A shows a schematic of the basic vapour absorption unit. The machine may be constructed in one, two or more shells or sections depending on the manufacturer or the application.

Unit Selection

The factors influencing the selection of an absorption machine are load, chilled water quantity, temperature of chilled water condenser water source, temperature and water quantity, fouling factor allowance, and heat source. The final selection is usually based on the least expensive combination of machine and cooling tower as well as a reasonable operating cost. The absorption can be utilised with any conventional open or closed circuit chilled water system.

Load, chilled water quantity and temperature rise are all related to each other so that, when any two are known, the third can be found by the formula:

$$\text{Load (tonnes)} = \frac{\text{Water Quantity (kg/s)} \times \text{Temperature (Deg.C)}}{3000}$$

The chilled water temperature should be carefully chosen. When low water quantities and a high rise (8 to 11°C) are required for the chilled water system, the use of two machines in series may be an economic advantage, since one machine operates at a higher level and requires less heat input.

Almost any good quality water is suitable for use in an absorption machine. Cooling towers are generally used, but river, lake or well water can also be used, when available in sufficient quantity and at the right temperature.

If the source is a lake, river, well or existing process water, the maximum expected temperature should be used in selecting the machine. The quantity required depends on temperature and load. When a cooling tower is to be used in conjunction with the absorption machine, the tower selection should be matched to the machine selection, to provide the most economical combination. In many cases, the optimum tower selection will indicate a condenser water temperature higher than the temperature normally estimated - usually 4 to 5°C above the designed wet bulb temperature. This may imply considerable saving in cooling tower cost by reducing the size of the tower. Since this is a heat-operated machine, the heat rejection to the cooling tower is approximately twice that of a motor-driven refrigeration machine.

The cooling tower used with the absorption machine is usually 75% larger than that used with the motor driven machine. The condenser water temperature drop through the tower is usually 10 to 11°C.

Typical fouling factor allowances are a minimum of 0.0005 for both system closed with chilled water and an open system with conditioned water.

Absorption machines normally use either low-pressure steam or high-temperature water as an energy source. The pressure or temperature limits are usually defined by the manufacturer, although 120psig steam pressure or a hot water temperature of 115°C and a temperature drop of 80°C are usually maximum values.

When the temperature or pressure exceeds the machine design limits, steam pressure reducing valve, steam-to-hot water converter, water-to-water heat exchanger, or a run-around system blending return water with supply water can be used to reduce the energy source to acceptable limits. Other sources that may be adapted for use are hot chemical solutions or petroleum.

When capacity requirements are less than machine capacity, a lower operating steam pressure should be considered. This permits a lower steam rate and total consumption. The condenser water quantity must be maintained at full nominal flow for this condition. This also may allow the machine to operate using low-pressure steam from a waste heat boiler.

Location

The location of the absorption machine directly influences the economic aspects of the system. A strong floor, fairly level, is required for locating an absorption machine. Other aspects of location include:

- Installation costs of piping between unit and equipment should be minimum.
- Sufficient space near machine for auxiliary equipment such as chilled and condenser water pumps and piping.
- Adequate clearances are necessary around the machine for access and servicing.

Many absorption machines are installed on upper floors or roofs of buildings.

Advantages of Absorption Chillers over Compression Chillers

The table gives important advantages of vapour absorption systems compared with vapour compression chillers.

Advantages of absorption chillers over compression chillers

Sl. No.	Compression chillers	Absorption chillers
1.	Input energy high grade Electrical energy.	Input energy low grade steam/hot water.
2.	Consist of many moving parts associated with high friction, hence more maintenance, less reliable.	Virtually no moving parts except for two small centrifugal pumps. Less maintenance, more reliable.
3.	Capacity control in steps for reciprocating compressors, hence exact load cannot be met with fluctuations in chilled water temperature.	Stepless, continuous capacity control.
4.	For centrifugal compressor, load below 20% causes surging causing danger to the machine.	No danger at capacities less than 20%
5.	Rugged foundations are required	Virtually no foundations are required.
6.	Machines work under high pressures. Hence any leak develops means loss of costly refrigerant	Machines operate under vacuum. Any leak developed will not release working substance.

Pinch Technology is a methodology, comprising a set of structured techniques, for the systematic application of the first and second laws of thermodynamics. The application of this technique enables process design engineers to gain fundamental insight into the thermal interactions between chemical processes and the utility systems that surround them. Having such knowledge enables the engineer to optimize overall utility consumption and set process and utility system configurations prior to final detailed simulation and optimization. These techniques are both simple and practical. This chapter illustrates how the application of Pinch Technology can provide the design engineer with the insight and understanding needed to evaluate complete process system designs.

Process heat and power integration has a significant impact on the overall process design. Therefore, it cannot be considered in isolation. It must be considered as an integral part of the system design or "synthesis". Many decomposition schemes have been proposed that break down the design of chemical process systems into subsystems, promoting a systematic and structured approach to synthesis.

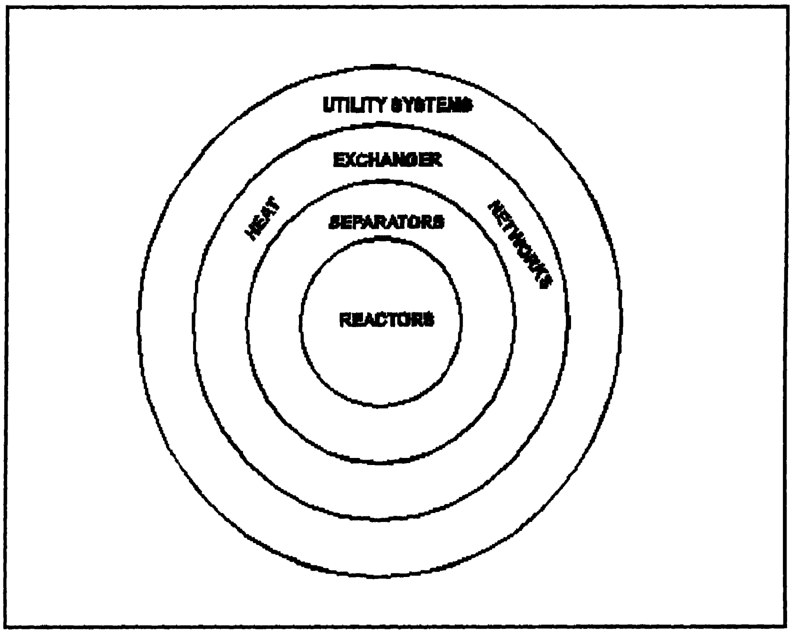


Fig. 1 : Subsystems in the Pinch Process

One such decomposition, schematically represented by Linnhoff in the "onion diagram"(1), Figure 1, breaks the total process system into four subsystems : the reaction system, the separation system, the heat exchanger network and the utility system. In this classic approach to synthesis, the first step is to set reaction conditions for optimum conversion and product yields. Second, a separation sequence is derived which will produce the products with the desired purities. This includes setting the pressure required to affect the separation and determining the required heating and cooling duties. Third, a heat exchange network is developed which integrates the heating and cooling duties. Finally, the utility system configurations are chosen to provide the net heating and cooling requirements.

As Linnhoff(1) pointed out, with such decomposition procedures the heat exchange network and the utility decisions are the last to be made. However, because heat integration does indeed impact earlier decisions, use of a decomposition approach must allow interaction between the decision levels, thus allowing earlier decisions to be modified to facilitate improved heat integration. Pinch Technology does just that.

Pinch Technology, a term introduced by Linnhoff and Vredeveld(2), has its origin in the work of Hohmann(3). Hohmann was the first to demonstrate that it is possible to establish design targets for minimum number of heat exchangers and minimum heat transfer area without committing to a heat exchanger network structure.

This concept was built upon by Linnhoff and Flower(4) in 1978 when they proposed the "problem table" representation for the temperature vs. enthalpy data and introduced the idea of a fixed minimum temperature difference for a given problem. The fact that a constraint to heat transfer existed within a process, now referred to as the "pinch", was discussed by Umeda *et al.*(5) in 1978. In 1979, Linnhoff *et al.*(6) added the concept of "cross pinch heat flow" which, in turn, led to the development of what are now called the "golden rules" of Pinch Technology. That was followed by the "appropriate placement"(7) concept for correct integration of heat engines, heat pumps, and distillation columns and the "plus/minus" principle(8) for screening process modifications. These basic principles have become the foundation of what we now call Pinch Technology.

A Universal Tank, or Uni-Tank, for short, is one in which a Universal Process, or Uni-Process, can be conducted.

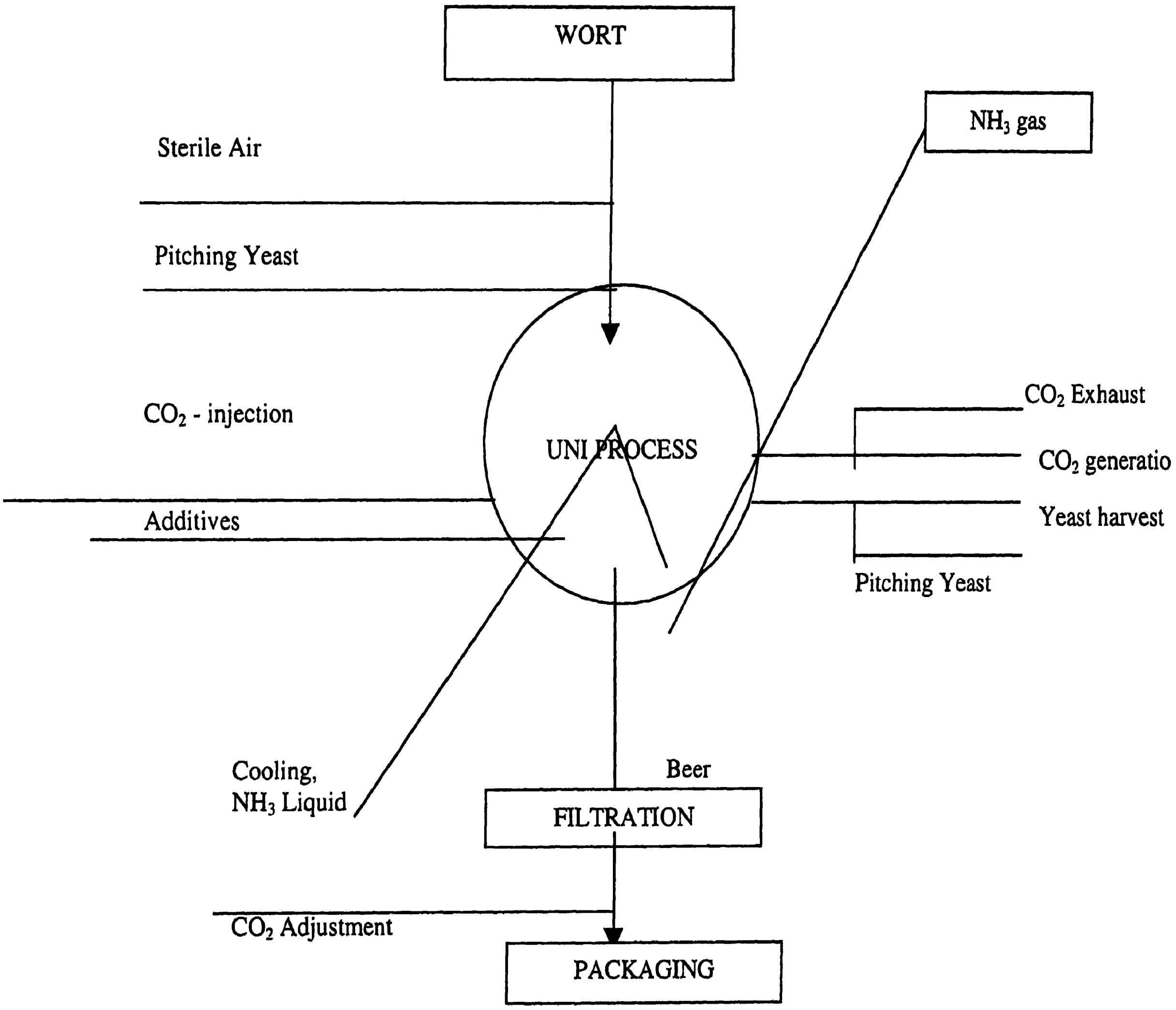


Fig. A: The Uni-Process

This is a wort-in, beer-out, large volume accelerated batch process. This concept offers substantial economic advantages, such as low capital investment, saving more than 50% of conventional operation cost and broad flexibility in operation.

The Uni-process in the Uni-Tank has proved to be successful in optimising cellaring processes. It does not require the fermenter, ageing tank and pressure tank sequence, but allows initiation and completion of the cellaring processes in one single Uni-Tank. If desired, the Uni-Tank may be used only as a fermenter, or only as an ageing or finishing tank, or as a combination of all three.

Table 1 : Available Options for Utilisation of Uni-Tank

<table>
<tr><th>Option</th><th>Fermentation</th><th>Ageing</th><th>Finishing</th><th>Process</th></tr>
<tr><td>1</td><td>Uni-Tank</td><td>Uni-Tank</td><td>Uni-Tank</td><td>Conventional</td></tr>
<tr><td>2</td><td colspan="2">Uni-Tank</td><td>Uni-Tank</td><td>Partial Uni-Pr.</td></tr>
<tr><td>3</td><td>Uni-Tank</td><td colspan="2">Uni-Tank</td><td>Partial Uni-Pr.</td></tr>
<tr><td>4</td><td colspan="3">Uni-Tank</td><td>Uni-Process</td></tr>
</table>

The Uni-Tank thus offers substantial versatility. The quality of the product obtained from Uni-Tank by Uni-Process is equal or better compared to the regular product.

The optimal size of the Uni-Tank depends on factors such as brewhouse capacity, product-mix, seasonal changes in sales, process time, smaller surface area heat transfer through the tank wall. Although spherical tanks would be ideal, their prohibitive construction costs force a compromise on cylindrical tanks with diameter equal to height, operated without counter-pressure. This tank is operated without counter-pressure.

This tank uses direct expanding liquid ammonia as a coolant. During the cooling period, CO_2 is bubbled upwards at the tank centre through injection ring. To reinforce the currents inside the tank for improved heat transfer and accelerated settling of yeast.

The advantages combine quality of product with lower capital investment and operation costs. These are:

i) Quality Related

- *Uniformity of product (dynamic system, no static conditions).*
- *Superior biological conditions (no transfer damage).*
- *One-floor operation, no basement (easy cleaning and maintenance).*
- *Shorter process cycle*
- *Pre-carbonation (no need for pressure tanks)*
- *Ease of supervision and quality control (larger volume, fewer analyses per barrel)*
- *Ready for full automation*
- *Less oxygen pick-up (no transfer damage)*

ii) Cost Related

- *Low initial investment (Rs.600-700 per barrel).*
- *No counter-pressure required (cheaper plates).*

- *Small surface-to-volume ratio (Less material per barrel).*
- *Substantial operational savings (less handling and maintenance, shorter process time).*
- *Speedy construction.*
- *Flexible tank utilisation (less foaming, easy to change).*
- *Reduction of beer losses (improved recovery by design).*
- *Liquid ammonia as refrigerant (less coolant costs per barrel produced).*

A variety of fuels are available for boiler firing, which must be selected keeping various factors, such as availability, storage, handling, emissions and of course, cost, in view. The type of fuel burnt in a boiler makes a difference in the energy efficiency. Each conventional fuel differs from the other in its inherent combustion characteristics, and this influences heat transfer. Various grades of oil are used as fuel in a boiler. The heavier, more viscous fuel oils cause problems in storage, handling, combustion and environmental pollution.

Storage

It can be potentially hazardous to store furnace oil in barrels. A better practice is to store it in cylindrical tanks, either above or below the ground. Furnace oil, that is delivered, may contain dust, water and other contaminants. The oil is agitated during prolonged storage to avoid clogging due to the presence of contaminants.

Preparation

Furnace oil is freed from contaminants before being pumped to the combustion system by installing a mesh of 10mm size to enable free-flow. The different sizes of strainers to be located at various points are shown in the table below :

Table 1 : Mesh Sizes for Strainers

Location	*Mesh Size*	*Holes/Linear Inch*
Between rail/tank lorry decanting point and main storage tank	*10*	*3*
Between service tank and pre-heater	*40*	*6*
Between pre-heater and burner	*100*	*10*

The viscosity of furnace oil and LSHS increases with decrease in temperature, which makes it difficult to pump the oil. To circumvent this, preheating of oil is accomplished in two ways: a) the entire tank may be preheated. In this form of bulk heating, steam coils are placed at the bottom of the tank which is fully insulated; b) the oil can be heated as it flows out with an outflow heater.

Bulk heating may be necessary if flow rates are high enough to make outflow heaters of adequate capacity impractical, or when a fuel such as Low Sulphur Heavy Stock (LSHS) is used. The recommended preheat temperature for pumping is given below:

Table 2 : Pumping Temperatures

Oil Grade	Preheat Temperature (°C)
Diesel / LDO	No preheating required
LSHS	70
Furnace oil	105

Fuel firing

Liquid fuel must be atomised prior to vaporisation and mixed thoroughly with the combustion air supply. A good burner should have a high turn down ratio. This is the ratio of the maximum to minimum fuel input rates with which the burner will operate satisfactorily. The maximum input rate is limited by the flame 'Blow Off' which results when the velocity of the mixture exceeds the flame velocity. The minimum rate is limited by a phenomenon known as 'Flash Back', which results the flame velocity, exceeds the mixture velocity. The selection of burners depends on the type of fuel used for combustion.

Atomisation is accomplished mechanically or with air/ steam. The oil can be atomised properly only when it is at the right temperature and hence, at the right viscosity. At a lower temperature, the droplets are too big producing soot and smoke. At a higher temperature, the droplets can be too small, passing through the flame too rapidly to burn. In neither case is the full energy content of the fuel used, and causing fouling of heat transfer surfaces. Generally the classification of oil burners is based on the dynamics of droplet formation. The following are the main types of oil burners :

- *Pressure jet atomising burners*
- *Twin-fluid atomising burners*
- *Horizontal rotary atomising burners*

Combustion and Combustion Equipment

In any combustion process, the chemical combination of oxygen with the combustible part of the fuel results in the release of heat. The requirements of a combustion process are fuel, oxygen and the three `T's, *viz.*, Time, Temperature and Turbulence

The most commonly used fuels in a furnace are oil, gas and coal. Adequate time and turbulent mixing of fuel and air ensure complete combustion. The most important component in the combustion of fluid fuels is the burner. The main purpose of a burner is to atomise and project the fuel into the combustion chamber.

The principal characteristics of a burner are:

a) Turn-down ratio: is the ratio of the maximum to minimum fuel, input without affecting the excess air level.
b) Flame Shape: The relative velocities of the fuel and air streams determine the flame length and shape. High velocities aided by good mixing (turbulence) produce a short bushy flame. Low velocities and delayed mixing result in long hazy flames. High pressures tend to throw the fuel away from the burner nozzle, before it can reach the ignition temperature, which lengthens the flame.
c) Flame Stability: is maintenance of ignition under varying conditions of low temperatures, input rates and fuel-air ratios. It may be enhanced by swirl or jet tubes.
d) Drive: relates to the velocity and thrust of the jet stream of hot gases that are thrown into a furnace. High velocity burners facilitate re-circulation of the gases, thereby improving the forced convection. Another advantage of high velocity burners is their ability to reach and wrap around parts of a load that are located at a distance from the burners.

Combustion Control Systems

Accurate and responsive control over combustion is essential to maximise furnace efficiency and ensure safe operation over a wide range of load. Fuel and air must respond rapidly to the rate of heat removal from the furnace by the load, if temperatures and pressures are to be maintained at optimal values and within safe limits. Fuel and air must also be carefully regulated with respect to each other, to prevent smoke formation, avoid explosion hazards and minimise stack losses.

Once combustion is established, the correct air - fuel ratio must be maintained. Insufficient airflow may form combustible gas pockets, which could be a potential cause of explosions.

The airflow should be sufficient to match combustion requirements of the fuel, and a small amount of excess air needs to be admitted to cover imperfect mixing, while promoting air and fuel distribution. In addition to these precautions, it is important to verify boiler water levels. Combustion should never be established until it is ensured that adequate cooling water is present in the tubes and steam drum.

Controls for smaller units manipulate fuel flow directly, to regulate process temperature or pressure, with air registers fixed or linked mechanically to the fuel-metering device. This arrangement can be satisfactory for fixed-load furnaces, but cannot maintain an efficient fuel/air ratio over a range of loads. The control of furnace draft, by manipulating a stack damper, helps to solve the problem, but does not eliminate it. The incorporation of heat-recovery devices such as economisers and air pre heaters has increased furnace pressure drop to the point where both induced-draft and forced-draft fans are needed to move the air and flue gas. The additional power provided reduces the self-regulating characteristics of air flow and necessitates air-flow metering and control. Combustion control systems can be classified as series, parallel and series/parallel.

In series control, either the fuel or air is monitored and the other is adjusted accordingly. For parallel control systems, changes in steam conditions result in a change in both air and fuel flow. In series/parallel systems, variations in steam pressure affect the rate of fuel input; simultaneously the combustion airflow is controlled by the steam flow.
Some of the important combustion related problems are discussed below:

Incomplete combustion

The main constituents of any fuel that burns producing heat, are carbon, hydrogen and sulphur. Combustion is an oxidation process of these elements, involving an exothermic reaction.

Incomplete combustion can arise from a gross shortage of air or surplus of fuel or poor distribution of fuel, generally by accident, rather than from a continuous operational defect. It is usually obvious from the colour of smoke, and must be corrected immediately. However, if the fuel is gas, the product of incomplete combustion is CO, which is invisible.

With coal firing, unburned carbon can comprise a big loss. It occurs as grit carry-over or carbon-in-ash and may amount to more than 2% of the heat supplied to the boiler. Non uniform fuel size could be one of the reasons for incomplete combustion. In chain grate stokers, large lumps will not burn out completely and pieces too small and fines may block the air passage, thus causing poor air distribution. In sprinkler stokers, stoker grate *condition, fuel distributors, wind box air regulation and over-fire systems can affect carbon loss. Increase in the fines in a pulverised coal firing system increases carbon loss.*

In the case of oil and gas fired systems, CO or smoke (for oil fired systems only) with normal or high excess air indicates burner system problems. For oil fired shell boilers, unburnt solids in the flue gas should be below 0.4% of the fuel fired.

A more frequent cause of incomplete combustion is the poor mixing of fuel and air at the burner. Local streams of rich and lean mixture may persist until a change of direction occurs. This effect can also result from the chilling of the flame, if it impinges on relatively cool surfaces, thus quenching the reactions, until a change of direction forces recombination. Poor oil fires can result from improper viscosity, worn tips, carbonisation on tips and deterioration of diffusers or spinner plates. Improper air registers and deterioration of burner throat refractory can increase losses due to presence of combustibles in flue gas.

In gas fired units, the vaporised light oil contained in the gas can condense, when the gas is expanded in a pressure reducing station. The condensed oil can carbonise in the gas burner and cause poor fuel distribution. Unbalanced fuel or air distribution in multi-burner furnaces can also result in high CO formation.

Low excess air would also leads to increased CO, smoking or solid combustible content of fly. This cause may again be control system related or may result from the inability of the fans to deliver enough air, because of increased flow resistance through heat recovery equipment, obstructed inlet screens or dirt on air foil blades.

High excess air

High stack oxygen and increased draft and pressure losses through the unit indicate high excess air. The fan power also increases. The problem could be due to high excess air settings or problems in the operation of the combustion system. The latter could be low fuel supply pressure in oil or gas firing, change in fuel heating value or viscosity not being compensated for, in a simple combustion control system. Leaking or plugged sensing lines in control systems may cause errors in fuel : air ratio settings.

The theoretical or stoichiometric amount of air is the minimum air required to burn fuel completely, so that carbon, hydrogen and sulphur are converted to CO_2, H_2O and SO_2 respectively. The following table gives the theoretical combustion air required for various types of fuel :

Table 1 : Theoretical Combustion Data - Common Boiler Fuels

Fuel	Kg of air req./kg of fuel	kg of flue gas/kg of fuel	m^3 of flue/kg of fuel	Theoretical CO_2% in dry flue gas	CO_2% in flue gas achieved in practice
Liquid Fuels					
HSD	14.04	-	11.53	15.6	11-13
Furnace Oil	13.90	14.30	11.50	15.0	9-14
LSHS	14.04	14.63	10.79	15.5	9-14
Gaseous Fuels					
Blast furnace gas	0.80	2.25	1.5	25.5	15-22
Butane	37.47	39.70	32.9	14.0	9-13
Coal gas	6.11	6.27	5.4	10.7	6-10
Coke oven gas	6.11	6.75	5.8	11.2	7-11
Natural gas	11.58	12.39	10.5	11.8	7-11
Producer gas	1.76	2.09	1.6	19.0	11-12
Propane	29.27	31.20	26.0	13.7	9-13
Water gas	9.18	3.37	2.7	18.0	10-15

With high excess O_2, some fuel is used to heat unnecessary excess air to the stack temperature, which is carried out through the stack, resulting in higher dry flue gas losses and reduced efficiency. Although the peak boiler efficiency occurs close to the minimum (stoichiometric) O_2, it is not practical to operate the boiler at this condition, unless it is equipped with highly sophisticated combustion control and flame quality monitoring to prevent any small deviations into unsafe or unacceptable combustion conditions. Hence, the boiler must be operated with some margin over the minimum oxygen level to accommodate normal variation in fuel properties, atmospheric conditions and other operational factors.

The optimum excess air level for maximum boiler efficiency occurs when the sum of the losses due to incomplete combustion and loss due to heat in flue gases is minimal. This level varies with furnace design, type of burner and fuel and process variables. It can be determined by conducting tests with different air-fuel ratios. Typical values of excess air supplied for various fuels are given below.

Table 2 : Excess air levels for different fuels

Fuel	Type of Furnace or Burners	Excess Air (% by Wt)
Fuel Oil	Oil burners, register type	5-10
	Multi-fuel burners and flat-flame	10-30
Acid sludge	Cone and flat-flame type burners, steam-atomized	10-15
Natural, Coke-oven, and refinery gas	Register-type burners	5-10
	Multi-fuel burners	7-12
Blast-furnace gas	Inter-tube nozzle-type burners	15-18

Wood	Dutch over (10-23% through grates) and Hofft type	20-25
Bagasse	All furnaces	25-35
Black liquor	Recovery furnaces for draft and soda-pulping processes	5-7

If the air flow rate is too high, the loss of heat to the flue increases, as also the running cost. Similarly, if the airflow rate is too low, a proportion of the fuel will remain unburnt, smoke appears in the flue gas and the running cost again increases. Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximate 0.6 % rise in efficiency.

Boiler Operating Efficiency Parameters

Most boilers used in breweries are furnace oil or HSD fired. Boiler designs are influenced by fuel characteristics and firing method, steam demand and steam pressure. The boiler for a certain application is specified by its total capacity to hold water and the rate of generating steam. Increasing boiler efficiency will involve minimising various energy losses in its operation. Determining of boiler efficiency will require an assessment of the various losses in the system as shown in Table 1.

Table 1 : Calculation of Boiler Efficiency

	kcal/h	%
Energy Input :		
Heat value in fuel	(A)	
Sensible heat in combustion air	(B)	
Sensible heat in fuel	(C)	
Total (P)	(A+B+C)	
Energy Output :		
Dry flue gas losses	(D)	
Losses due to moisture in fuel	(E)	
Losses due to Hydrogen in fuel	(F)	
Losses due to moisture in combustion air	(G)	
Losses due to unburnt ash and flyash	(H)	
Surface heat losses	(I)	
Blow-down losses	(J)	
Total (Q)	(D+E+F+G+H+I+J)	
Overall thermal efficiency (X)	$\frac{Q}{P} \times 100$	

Performance Evaluation of a Boiler

Fuel is a major cost in boiler operation. It is therefore important to minimise fuel consumption and maximise steam production. Although boiler efficiency is primarily a design parameter, the operator can maintain or significantly improve efficiency by controlling heat losses in the stack and ash pit. A typical heat utilisation pattern in a boiler is represented below: The evaluation can be carried out by the direct or indirect method as explained below :

Direct method

This is also known as 'input-output method' due to the fact that it uses/ needs only the useful output and the heat input (i.e. fuel) for evaluating the efficiency. Thus the efficiency can be evaluated using the formula:

$$\textit{Boiler Efficiency} = \frac{\textit{Heat output}}{\textit{Heat Input}}$$

$$= \frac{\textit{Steam flow rate x (Steam enthalpy - Feed water enthalpy)}}{\textit{Fuel firing rate x Gross calorific value}}$$

Advantages:

- *Plant people can evaluate quickly the efficiency of boilers*
- *Requires few parameters for computation*
- *Needs few instruments for monitoring*

Disadvantages:

- *Does not give clues to the operator as to why the efficiency of the system is lower*
- *Does not calculate the various losses accountable for various efficiency levels*

Indirect method

The disadvantages of the direct method can be overcome by this method, which calculates the various heat losses associated with boiler. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. This method is also known as the heat loss method.

The various losses in the normal operation of a boiler are discussed in detail.

Dry flue gas loss (L_{dfg})

Normally, the major heat loss occurs through the flue gases, which escape out at a higher temperature. To minimise losses in a coal fired plant, proper combustion is essential with better fuel preparation, stoking practices and improved control of combustion air. Burners should be undamaged and properly maintained. Combustion air, both primary and secondary should be introduced at the right rate and with adequate turbulence. Fuel preparation should be proper. Dry flue gas loss depends on two factors viz. the flue gas temperature and quantity of flue gas. The flue gas quantity depends on the excess air level, which is in turn related to the fuel used. The excess air level can be found by using the formula:

$$\text{Excess air in flue gas (EA)} = \frac{O_2}{21 - O_2}$$

Where O_2 = % oxygen in flue gas

$$\text{Total quantity of air } (M_a) = (1 + EA) \times M_f \times A_t$$

Where M_a = Air flow rate (kg/h)

M_f = fuel consumption (kg/h)
A_t = theoretical air requirement (kg/kg)

Dry flue gas quantity (M_{fg}) = $M_a + M_f$ kg/h
Dry flue gas loss (L_{dfg}) = $M_{fg} \times C_p \times (T_g - T_a)$ kCal/hr

Where C_p = specific heat of flue gas (kCal/ kg°K)
T_g = flue gas temperature at economiser/ air preheater outlet (°C)
T_a = ambient temperature (°C)

Loss due to moisture and hydrogen in fuel ($L_{mf,hf}$)

The moisture content in fuel and air and the hydrogen content in fuel also affect the efficiency of the steam generating system.

$$L_{mf,hf} = \frac{Mwf}{18 \times 100} + \frac{H}{2 \times 100} \times Mf \times \{8.276 \times (T_g - 100) + (100 - T_a) + 9717\}$$

Where M_{wf} = Moisture in fuel (% wt in fuel)
H = Hydrogen in fuel (% wt in fuel)

Loss due to moisture in air (L_{ma})

Moisture in air (k.mol/h) (based on dry bulb and wet bulb temperatures)

$$M_{wa} = \phi_m \times (M_a / 28.84)$$

Where, ϕ_m = Molal humidity (kmol/kmol dry air)
M_a = Total quantity of air (kg/h)

Loss due to moisture (L_{ma}) = $M_{wa} \times \{ 8.276 \times (T_g - T_a)\}$

Loss due to carbon monoxide (CO) in flue gas (L_{co})

Though sufficient combustion air is fed for the combustion of fuel, it is always possible that, due to the non-mixing of fuel with air or ingress of cold air freezing the reaction, the carbon present may burn partially to form CO. Each kilogram of CO formed means a loss of 5654 kCal of heat.

$L_{co} = M_{co} \times 5654$
CO formation (M_{co}) = CO (in ppm) $\times 10^{-6} \times M_f \times 28$

In the case of coal or oil fired boilers, this condition can be detected by the presence of dark smoke in the stack gases. The heat loss, measured in terms of the non-conversion of carbon into carbon dioxide, is relatively small, but the rapid fouling of heat transfer surfaces adversely influences the boiler performance.

Total flue gas loss = (a) + (b) + (c) + (d)

Unburnt losses (Lu_{ubc})

Apart from the partially oxidised carbon monoxide in the flue gases, some un-burnt carbon is present in ash in case of solid fuel firing. The extent of un-burnt carbon is a factor of type of solid fuel handling system. This loss generally varies from 2% to 5% . It is a clear indication of combustion air starvation, which can be caused by poor air distribution under the grate , too thick a fire bed and uneven bed thickness resulting from poor stoking practices. The samples of ash containing un-burnt carbon should be collected as per IS specifications and then analysed in the laboratory for the un-burnt carbon content. This gives a fairly good estimate of the losses, that are normally unnoticed by the plant.

Loss due to unburnt carbon in ash $(L_{ubc}) = (M_{ubc} / 100) \times M_f \times 8064$

Where M_{ubc} = % mass of unburnt carbon in ash

Sensible heat loss in bottom ash (L_{sa})

In coal fired boilers, the ash is removed from the furnace bottom at a temperature which varies between 250-300°C. This heat loss normally forms very small percentage of the total heat loss (usually 0.5 to 1%) and is unavoidable in solid fuel firing.

Sensible heat loss in bottom ash $(L_{sa}) = [M_a+((M_{ubc}/100) \times M_f)] \times C_{pa} \times (T_{ba} - T_a)$

Where, M_a= quantity of ash generated (kg/h)
C_{pa}= specific heat of bottom ash (kCal/kg°C)
T_{ba}=Temperature of bottom ash while removed from the furnace (°C)
T_a = ambient temperature (°C)

Blowdown loss (L_{bd})

Blowdown is done in all boilers to maintain the total solids content within the prescribed level. Depending on the boiler pressure and type, this limit varies. The blowdown can be continuous, intermittent or both. The loss is between 1% and 6% and depends on a number of factors :

- total dissolved solids (TDS) permissible in the boiler water
- quality of make-up water, mainly dependent on water treatment method used
- amount of uncontaminated condensate returned to the boiler house
- boiler load variations

The heat loss due to the blow down can be calculated as :

Heat loss due to blowdown = $M_{bd} \times (h_{fbd} - h_{fw})$ kCal/h

Where, M_{bd} = quantity of blowdown (kg/h)
h_{fbd} = enthalpy of blowdown water at boiler drum pressure (kCal/h)
h_{fw} = enthalpy of feed water (kCal/h)

Structural loss (L_s)

Structural loss = Radiation loss + Convection loss

Radiation loss:

$S_r = B \times E \times A \times (T_s^4 - T_a^4) \times 860/1000$

B = Stefan Boltszmann constant

E = emissivity of the surface

A = surface area (m^2)

T_s = surface temperature (°K)

T_a = ambient temperature (°K)

Convection loss:

$S_c = h \times A \times (T_s - T_a) \times 860/1000$

h = Heat transfer co-efficient (kCal/h. m^2.°C)

Total heat loss = Flue gas loss + Unburnt loss + Sensible heat in Ash +Structural loss + Blow down loss

Thermal efficiency of the boiler (%) = $\dfrac{\textbf{(Heat input per hour - Total heat loss) x 100}}{\textbf{Heat input per hour}}$

Retrofitting Combustion Control Systems

Microprocessor based combustion control for boilers have been developed recently. These have emerged as continuous on-line sensors that measure and display the gas temperature, oxygen, combustion efficiency etc. This leads to a better understanding of the equipment performance and achieves quantitative energy conserving controls.

The system consists of an oxygen sensor system, electronic and airflow control system. The oxygen sensor system has a zirconium cell based, probe type sensor, located at the furnace hot zone. The oxygen set point is programmable. Depending on the actual oxygen in the flue gas, airflow is controlled to achieve an optimum air to fuel ratio. The system can be fitted on to existent burner systems, without disturbing other process controls. It eliminates the deficiencies of traditional ratio-controllers and mechanical linkages, by substituting them with electric or pneumatic systems. More advanced systems include pressure ratio control of the fuel and air, direct air and fuel metering and excess air correction systems using flue gas O_2 *monitoring. Some of the applications of these sophisticated control systems have been limited by their cost, reliability and maintenance requirements.*

Fuel Efficient Burners

Commercially, these burners offer a turn down ratio of 7:1 and operate at low excess air levels. They are available in a wide range of sizes varying from 20 l/h to 220 l/h. They can handle all types of liquid fuels, from kerosene to heavy fuel oils such as furnace oil, LSHS and RFO. These burners are easy to clean and can be refitted immediately, thus reducing maintenance cost and shut down time. When existing burners are replaced, accessories such as the air blower, burner block, etc do not need replacement. There are various types of fuel efficient oil burners :

- *High velocity burners*
- *Self-recuperative burners*
- *Regenerative burners*
- *Flat flame burners*
- *Pulsating combustors*

Low Excess Air Burners

These were originally developed in Europe and employ improved oil fuel atomisation and controlled air fuel mixing to achieve extremely low excess air (3-5%) operating levels. Pollution levels are also significantly reduced. Retrofitting of these LEA burners have had *some problems, relating to the compatibility of new flame shapes and heat release rates with existing furnace volume and design. LEA burners require a very sophisticated combustion control system that employs automatic oxygen correction, to fully utilise its low excess air capability and prevent small excursions in excess air that might lead to high combustibles and potentially unsafe conditions.*

High exit gas temperatures at normal excess air indicate poor heat transfer performance. This condition can result from a gradual build-up of gas-side or waterside deposits. Waterside deposits require a review of water treatment procedures and tube cleaning to remove deposits.

Gas-side deposits result from normal ash accumulation on heat transfer surfaces or formation of excessive amounts of carbon in oil-fired units. When conditions do not permit complete combustion, deposition of unburnt particles, known as soot, results, especially with heavier fuels. Ash deposits, significant with solid fuels, may build up in high temperature zones, such as the super-heater, due to melting of certain low melting point components of the fuel ash. These deposits result from too high gas temperatures at these points or poor combustion conditions such as poor atomisation. These deposits tend to be corrosive. Increased draft loss through the boiler, economiser or air heaters may also indicate heavy deposits.

Soot-blowers are normally installed on coal-fired units and on many heavy oil fired units. If soot blowers operate effectively, a decrease in exit gas temperature should be observed after their operation. Visual examination of deposit patterns, during a shutdown, may disclose the need for increased soot-blower pressure or their relocation to provide more effective cleaning. The deposits build up over a period of time, hindering heat flow and resulting in a higher flue gas temperature and hence greater heat loss. An estimated 1-% efficiency loss occurs with every 40°F increase in stack temperature. Stack temperature should be checked and recorded regularly as an indicator of soot deposits. When the flue gas temperature rises about 20°C above the temperature for a newly cleaned boiler, it is time to remove the soot deposits. It is, therefore, recommended to install a dial type thermometer at the base of the stack to monitor the exhaust flue gas temperature.

Every mm thickness of soot coating increases the stack temperature by about 55°C. It is also estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5%. Periodic off-line cleaning of radiant furnace surfaces, boiler tube banks, economisers and air heaters may be necessary to remove stubborn deposits. Washing of rotary air heaters is recommended when draft losses increase by an inch of water gauge.

In the low temperature zones of the boiler, e.g. at the economiser, the air pre-heater and the induced draft fan, corrosion deposits due to condensation of sulphur trioxide, present in the flue gas, can also occur, if the temperature falls below the dew point temperature of the flue gas.

CFC (chlorofluorocarbon) chemicals have been common refrigerants used in refrigeration and air-conditioning systems for more than fifty years. But CFCs released into atmosphere by leakage or venting out have a tendency to deplete the earth's protective ozone layer and release " greenhouse gases". The ***Montreal Protocol*** calls for the replacement of CFCs by environment - friendly refrigerants by all nations by the year 2015 A. D.

The ideal CFC replacement would be one that could be substituted in an existing refrigeration and air conditioning system without any modification. So far, no such replacement has been found.

The most promising development is R134a, a substitute for R-12, but R134a is less efficient than R-12, five to six times more expensive and needs special synthetic polyester lubricants, as it is not totally miscible with mineral oil. The gear set also has to be changed for retrofitting the refrigeration and air conditioning system, to maintain its capacity, with nearly the same power consumption. R134a belongs to a group of compounds known as HFCs (Hydrofluorocarbons). HFCs were thought to be more ozone-friendly, but have now been identified as being more harmful than CFCs and these too need to be phased out. Common HCFC refrigerants developed includes R-123 and R-22. R-123 is less efficient than CFC R-11 due to greater mass and lowers chiller capacity by 10-20%.

R152a and hydrocarbon applications are limited in many countries by flammability concerns and regulations. The European domestic appliance industry is using hydrocarbons in many units, currently being manufactured (Carpenter, 1996).

Refrigeration and air conditioning systems are set to undergo major changes in the coming decade. The possibilities can be development of less efficient refrigerants than CFCs, vapour absorption systems or leak minimisation and refrigerant recycling in CFC systems.

Appendix 15 : Properties of Insulating Materials

Name of material	Thermocole Polystyrene	Cork	Foam Glass	Resin bonded glass wool	Resin bonded mineral wool	Saw dust and rice husk	Resin bonded fibre #
Common form	Slabs and pipe covering	Slabs	Slabs	Slabs and pipe covering	Slabs and pipe covering	Loose fill	Slabs and boards
Density (kg/m^3)	15- 30	120 - 160	130	24 - 48	48 - 80	120 - 250	250 - 400
a. Thermal conductivity at 10°C (kcal/m/h°C)	0.028 at 18 kg/m^2 0.026 at 27 kg/m^2	0.036 at 160 kg/m^2	0.047 at 127 kg/m^2	0.035 at 24 kg/m^2 0.032 at 32 kg/m^2 0.027 at 48 kg/m^2	0.035 at 48 kg/m^2 0.027 at 80 kg/m^2	0.060 at 120 kg/m^2 0.050 at 150 kg/m^2 0.058 at 200 kg/m^2	0.043 at 250 kg/m^2 0.053 at 350 kg/m^2
b. Diffusivity (m^3/h) 10^{-3}	2.5	0.65	1.25	2.80	1.60	0.60	0.62
Working temperatures,°C							
Maximum	+ 75	+ 90	+ 400	+ 150	+ 150	+ 90	+ 90
Minimum	- 200	- 150	- 100	- 30	- 30	+ 5	+ 5
Water vapour transmission rate (permeance (g/m^2.24h. mmHg)	0.40	1.70	0.03	8.5	8.5	14.3	17.5
Water absorption :24 h immersion (percent by Weight)	0.30	4.9	0.08	2.3	2.3	42.5	13.7
Advantages	Clean, light weight, easy to work and excellent water transmission resistance	Resilient and can be handled easily	Excellent water transmission resistance	Being an inorganic material possesses high fire resistance	Being an inorganic material possesses high fire resistance	Raw material is very cheap	Easy to handle
Disadvantages	Inflammable	Imported	Not easily available	-	-	It is highly hygroscopic	Highly hygroscopic

Anaerobic treatment processes are employed extensively in the treatment of concentrated waste streams. This treatment technology encompasses degradation of organic matter in the absence of oxygen. The most important merits of anaerobic treatment over aerobic treatment are

- The ability to treat high strength wastewater
- Low energy input
- Low sludge generation
- Low nutrient requirement
- Low operating costs
- Low space requirements
- Net benefit of energy generation in the form of biogas generation

Anaerobic digestion enables collection of biogas. In this process, organic materials, in mixtures of primary settled and biological sludge, are converted biologically, under anaerobic conditions, to various end products including methane and carbon dioxide. The process is carried out in an airtight reactor. Sludge, introduced continuously or intermittently, is retained in the reactor for varying periods of time. The stabilised sludge, withdrawn continuously or intermittently from the reactor, is reduced in organic and pathogen content and is non-putrescible.

Organic matter is represented in terms of Biological Oxygen Demand (BOD), which varies from industry to industry. Anaerobic digestion is found to be successful even with effluents containing BOD of 500 mg/L. Theoretically, 1 kg of ultimate BOD (Oxygen demand met to destabilise the organic matter totally) yields 0.35 m^3 of methane, which has a net heating value of about 35,800 kJ/ m^3